OPTIMIZATION OF TURKISH AIR FORCE SAR UNITS' FORWARD DEPLOYMENT POINTS FOR A CENTRAL BASED SAR FORCE STRUCTURE

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Abstract

Many developed countries that have a combatant Air Force and Search & Rescue (SAR) assets designed for their Air Force's SAR service have been struggling with locating SAR units due to limited SAR assets, constrained budgets, logistic-maintenance problems, and high risk level of military flights. In recent years, the Turkish Air Force (TUAF) has also been researching methods to gather all SAR units into a central base and deploying the needed number of SAR units to defined Deployment Points (DPs).

This research applies three location optimization models to determine the optimum locations for TUAF SAR units. The first model, Set Covering Location Problem (SCLP), defines the minimum number of SAR DPs to cover all fighter aircraft training areas (TAs). The second model, Maximal Covering Location Problem (MCLP), aims to obtain maximum coverage with a given SAR DP number and response time. A weighted MCLP models is also applied with TAs risk values obtained by this research to maximize demanded coverage of TAs. Finally the last model, P-Median Location Problem, defines the locations of SAR DPs while obtaining minimum aggregate or average response time. These three models are applied via a Visual Basic for Applications (VBA) & LINGO Optimization Software interface that allows changing each exogenous variable of the models in a flexible way.

The primary objective of this research is to provide the information for the required number of SAR units and their locations. The results indicate that the response time definition is as important as the required number of DPs. Additionally; some DP locations are indispensible because they have no alternative in their sectors.

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To the hidden hero of my life, my beloved wife, that did great sacrifices for me and to my little sons of whom I wasted the game time to study, thanks for your understanding and patience. To my mother and father for their infinite support at all the phases of my life. I love you all.

Acknowledgments

This research does not contain the official policy of the Turkish Government or Turkish Air Force about deciding the locations of Search and Rescue units. All the demand points and candidate points are chosen by me to generate a scenario map. The illustrated maps are only for demonstration of research's methodology and results, not for implementation. I am solely responsible for all the comments and critiques in this research.

I would like to express my sincere thanks to my thesis advisor, Dr. Jeffery D. Weir for his very helpful and understanding manner. The completion of this research would not be possible without his sustained support and deep knowledge. And also, I am grateful to Maj. Jennifer L. Geffre who has given great support in every issue during my education in AFIT.

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I. Introduction

1.1 Overview

1.1.1 Turkey's Location & Policy

Turkey is one of the developing and strong countries in her located geographical area. Existing on an area as a bridge between Europe and Asia, in other words western and eastern civilizations, makes her importance worldwide. While the position of Turkey poses importance in terms of connection of cultures and civilizations, it reveals a rough neighborhood and some threats as expected. Hence, as a guarantor of peace and stability in this critical region she should keep herself always strong enough to counteract the threats that may appear around her mainland. To be a powerful country today means that a country is strong enough in the political, economical and military areas. Having powerful armed forces becomes a very vital capability in such threat containing areas like Middle East or Balkans.

When we evaluate our present day technology, aviation and space studies arise as some of the most outstanding and promising power factors. Armed forces without air power and air defense systems are not able to defend their own borders and populace from an external aggressor as well (Alkanat, 2008). In light of this evaluation (NATO MCASB, 2015), Turkey knows that she should have a powerful Air Force to have powerful armed forces. The tremendous effort of Turkey in keeping her Air Force talented and powerful should be read as a method of deterring threats in advance.

1.1.2 Turkish Air Force (TUAF)

The Turkish Air Force (TUAF) is one the five branches of the Turkish Armed Forces with Turkish Army, Navy, Coast Guard, and Military Police. TUAF's main responsibility is preventing threats and dangers likely to be received via air against Turkey, and facilitating the way to success of the duties of Land and Naval Forces during a possible war (Turkish Air Force, 2010). TUAF's first goal is keeping up the level of contemporary Air Forces in the world to satisfy this responsibility.

TUAF has modern capabilities such as fighter, cargo, refueling aircraft, and helicopters to operate effectively both in day and night conditions. In addition, the facilities on which these capabilities are located are constructed in a very sophisticated structure to respond to the requirements of modern aviation. Turkey is also one of the stakeholders of the F-35-Joint Strike Fighter project. Furthermore, many organic production and modernization projects with training aircraft, Unmanned Air Vehicles (UAVs), munitions, and avionics systems have been supported by TUAF for the last few decades. It will be presumably true to express that TUAF is the best air force in its region today.

The efforts and the density in development activities of capabilities and facilities are also reflected in the intensity of flight operations in Turkish Air Space. Flight operations always include high-level risks. To mitigate these risks an air force should provide some services like air traffic control, civilian engineering activities of bases, search and rescue service etc. The increasing number of flights, especially fighter flights, in Turkish Airspace forces Turkish Air Force decision makers to generate a more effective Search and Rescue (SAR) system for TUAF.

1.1.3 SAR Service Necessity for an Air Force

Military flights are always accepted as one of the highest risk containing missions of a military. Since they are risky missions, most of the countries' military structures include SAR assets of which the primary mission is rescuing the military flight crew after an accident or an ejection from a fighter aircraft. It is especially important to make a pilot know that he will be rescued in case of an accident and ensuring he feels safe is a vital issue for an air force to keep morale and motivation of personnel at a high level.

Military flights are usually executed over seas and terrains out of residential areas. Hence, flight crews ejected because of an accident or a malfunction probably find them themselves in challenging terrain and weather conditions. It is also presumably not possible in these conditions to reach someone who can help you survive. Dangers such as freezing, hypothermia and drowning at sea, severe injuries occurring during contact with the rocky and wooded terrain, and injuries from misusage of parachutes make establishment of a SAR system in a way that survivors can be reached in the shortest time.

1.2 Background

1.2.1 SAR Definition

"Search & Rescue (SAR)", "Personnel Recovery (PR)", and "Combat Search & Rescue (CSAR)" are three terms that need to be distinguished in this subject. In the Lexicon Chapter, the final draft of Allied Joint Doctrine for Personnel Recovery in NATO Operations, (NATO MCASB, 2015), states that Search and Rescue is the location and recovery of persons in distress in an environment where hostile interference is not expected. The provision of SAR is a national responsibility operated to meet International Civil Aviation Organization (ICAO) and

International Maritime Organization (IMO) agreements. Another term appears in this subject, CSAR, defined as “Combat Search and Rescue: The detection, location, identification and rescue of downed aircrew in hostile territory in time of crisis and war and, when appropriate, isolated military personnel in distress, who are trained and equipped to receive combat search and rescue support” (Joint Air Power Competence Centre-JAPCC, 2011). This definition was in early 2000s NATO documents but then NATO developed a conceptual term, “Personnel Recovery”. Again, (NATO MCASB, 2015) defines PR as “sum of military, diplomatic and civil efforts to perform the recovery and reintegration of isolated personnel”. These definitions give us the exact difference between SAR and PR. Since our problem is about SAR locations of TUAF, we will evaluate all location options in terms of peace conditions.

1.2.2 SAR Activities of TUAF

The Turkish SAR plan is generated to be compatible with international military agreements. The SAR responsibility of the whole country (land and seas) is shared between civilian and military authorities such as Undersecretary of Maritime Affairs (UMA), TUAF, Turkish Army, and Turkish Coast Guard. In this plan, the responsibility of SAR activities of fighter flights has been given to TUAF SAR units located on air force bases. SAR operations consist of two phases, “search” and “rescue”. They are carried out via airplanes and helicopters. Medium ranged transport planes are used to locate the survivor in the searching phase of the operation in the case where electronic signals are not received by the SAR Operation Center. Helicopters are main assets of SAR operations. Their primary mission is to conduct the rescue phase. If the survivor is located via electronic signals of the personnel locating system (PLS) by the SAR Operation Center then the first phase is skipped. Otherwise, search airplanes are assigned to execute the first phase since they are faster than the helicopters.

In any case, airplanes and helicopters take off as soon as possible. Helicopters move to the approximate event zone while airplanes execute the searching phase. Developments in satellite based technologies for personnel locating usually provide the probability of skipping first phase.

The minimum SAR unit of TUAF located in a base consists of a few helicopters with 2 pilots, 1 hoist operator, and 2 SAR Specialist Commandos per helicopter. These numbers can be extended according to the frame of the mission.

1.2.3 Problem Statement

Many developed countries that have a combatant Air Force and SAR assets designed for their Air Force's SAR service have been struggling with locating SAR units due to limited SAR assets, constrained budgets, logistic-maintenance problems, and high risk level of military flights. The primarily problem faced by the Air Forces about SAR locations is finding an optimum number of units to maximize coverage on demanded areas while minimizing the cost and response times.

As a result of this dilemma, TUAF has been researching its SAR locations in recent years. A hundred percent coverage on demand points, which are fighter planes Training Areas (TAs), is the basic objective of its SAR location plan, but it doesn't seem to be possible with existing capabilities. Hence, TUAF authorities have been researching a method of gathering all SAR units in a central base and deploying the needed number of SAR teams to defined Deployment Points (DPs).

Generating this kind of a solution appears to be a more applicable method in terms of logistics and maintenance of helicopters. Also, it would be more beneficial for enlarged, joint

exercises for SAR crew training. However, some constraints such as the number of helicopters, pilots, crew are still present while defining SAR teams deployment locations.

Consequently, our study focuses on;

- defining the minimum number of SAR DPs to cover all TAs,
- obtaining maximum coverage with a given SAR DP number and response time,
- defining the locations of SAR DPs while obtaining minimum average response time,

in a deterministic approach in case of TUAF decision to gather all SAR units in a central base.

1.2.4 Assumptions and Limitations

The problem is mainly about locating SAR DPs in a deterministic approach. Logistical and basing problems are not in the scope of this study. Thus, in line with this information we assume the following:

- All the candidate points (DPs) have the same cost.
- Personnel, equipment, deployment schedule, and training requirements are not considered.
- Helicopters deploying to the DPs are all the same types and they all have same features.
- Central SAR base always has an SAR unit on duty. Hence, this base is forced to be one of the DPs in the mathematical models.
- Quick reaction time of a SAR team is 15 min.
- SAR Helicopter’s speed is 130 NM/Hr.

1.3 Summary

As mentioned above, the SAR location problem is an existing issue in terms of limited capabilities and increasing costs for all countries that have an Air Force. TUAF is also facing this problem. It has been trying to find a cost effective solution to locate its SAR units within an idea of central basing of all SAR assets and deploying them to demanded areas. This research optimizes deployment locations of TUAF SAR units by minimizing the response time and numbers of DPs within a given notional generic TA and DP scenario.

1.4 Conclusion

Chapter 2 gives a literature review about location problems and solution techniques used in this study. Chapter 3 describes the methodology of applying types of location problems to our problem area. Differences between these techniques and our models are shown as well. Chapter 4 interprets results and analyzes the differences between the three methodologies. Chapter 5 presents a general conclusion and advises some follow on topics.

II. Literature Review

2.1 General

This chapter presents general information about historical phases and types of location problems, methods to solve these types of problems, and the application of location problems in some military examples. The information about location problems is gathered from textbooks, articles, theses and other sources.

2.2 History of Location Problems

Location problems aim to find the optimum location, on a map, of facilities for demanded areas. These facilities can be some service points such as hospitals, police reaction points, airports, or Quick Reaction Alert (QRA) points for fighter aircraft. The location problems modeling mostly depends on demanded areas or points to cover and candidate points to locate facilities. A variety of demand and candidate points reveals a wide type and solution range that change according to the objective.

The location problem dates back to the 1600s. The first suggestion of the problem is usually accredited to Pierre de Fermat who came up with an idea of finding the optimum point, which is the closest distance to another given three points in a plane (Sarikaya, 2009). The first formally presented location problem, presented by Alfied Weber in 1909 (Alkanat, 2008), involved locating a single warehouse while minimizing the total travel distance between the warehouse and a set of spatially distributed customers. In the 1950s some researchers focused on location problems of facility layout but an initiative work in the field of location theory, commenced by Hakimi in the mid-1960s, consisted primarily of a number of separate applications not tied

together by a unified theory. He studied the general problem of locating one or more facilities on a network to minimize the travel distances (Brandeau & Chiu, 1989).

During the last 35 years, several comprehensive books in this area have been written. Interested readers can refer to the books stated below to find out more about typical facility location models: (Handler & Mirchandani, 1979), (Love, Morris, & Wesolowsky, 1988), (Francis, McGinnis, & White, 1992), (Daskin, 1995), (Drezner & Hamacher, 2002), (Nickel & Puerto, 2005), (Church & Murray, 2009), and (Farahani, SteadieSeifi, & Asgari, 2010). Since there are many different types of location problems, "for more than 120 years, mathematicians, analysts, operations researchers, and management science scholars have tried to devise algorithms and techniques to identify optimal locations given a wide variety of problem parameters, resource constraints, and model objectives." (Eberlan, 2004)

Today, applications of location problems spread to so many different areas. Dispatching the warehouses of a company, locating the shops of a market chain, finding optimum service stations for emergency service providers are some of the prominent examples for today's researchers.

2.3 Parameters of Location Problems

Location modeling decisions commonly depend on the measurements of distances proximity. Even distances from point to another are used; coverage method is another important alternative method. Some basic parameters in a location problem are "demand points", "candidate points", "distance matrix", and "response time".

Demand Point: A demand point is a point or area that should be serviced by the facility. To be serviced means that the demand point is under the coverage of one of the nearest facilities within the defined range.

Candidate Point: A candidate point is one of the alternative places to locate a facility. A candidate point can be either continuous or discrete, as our problem is discrete we will discuss the Discrete Network Location problem where a candidate facility site is known with certainty (Drezner & Hamacher, 2002).

Distance Matrix: A distance matrix is the basic tool for the establishment of a location study. This matrix shows the distances from each demand point to each candidate point. With the help of this matrix we are able to apply linear modeling techniques.

Response Time: Response time is the SAR unit reaction time including time to pass from a candidate point to a demand point. Since most of the location problems are related to some urgent services, another way of comparing facility-locating alternatives is response time. Decision makers would prefer to compare response times rather than distances, because the same distance may mean different response times in terms of using different assets, vehicles etc. Thus, location studies that include urgency generate their research according to response times.

2.4 Types of Location Problems

The general problem is optimizing some objectives while locating facilities. Distance or any other measure such as response time is fundamental to such problems. Thus, classifying location problems according to their consideration of distance is a good method, and is presented by Drezner and Hamacher in their book. (Drezner & Hamacher, 2002) They present information about eight basic facility location models and separate them into two quad groups. The first four are based on maximum distance and the second four are based on total (or average) distance. These models are explained in Table 1.

Table 1. Basic Facility Location Models

	Basic Facility Location Models	
	Model Name	**Model Objective**
Maximum Distance Models	**Set Covering Location Model-SCLP**	To locate the minimum number of facilities required to cover all of the demand points.
	Maximal Covering Location Model-MCLP	To locate predetermined number of facilities while maximizing demand points coverage.
	P-Center Problem	To minimize the maximum distance demand from its closest facility, given that there are a pre-determined number of facilities
	P-Dispersion Problem	To locate predetermined number of facilities while the distance between any pair of facilities is maximized.
Total or Average Distance Models	**P-Median Location Problem**	To locate predetermined number of facilities while minimizing the demand-weighted total distance between demand nodes and the facilities.
	Fixed Charge Location Problem	To minimize total facility and transportation costs while determining the optimum number and location of facilities.
	Hub Location Problem	To minimize total transportation cost while locating the hubs and delivery routes.
	Maxisum location problem	To locate predetermined number of facilities while maximizing demand weighted total distance.

As mentioned in the Chapter 1, this research will

- define the minimum number of SAR DPs to cover all TAs, which can be solved by the SCLP method,
- obtain maximum coverage with a given number of SAR DPs and a given response time, which can be solved by the MCLP method,
- define the locations of a given number of SAR DPs while obtaining minimum average response time, which can be solved by the P-Median method.

Hence, we present detailed information about the formulation and the parameters of these three methods.

2.4.1 Set Covering Location Problem-SCLP

The covering location problem is generally divided into two, the Set Covering Location Problem (SCLP) and the Maximal Covering Location problem (MCLP). The SCLP method gives the minimum number and locations of facilities to cover all of the demand points. The optimal number of facilities is determined within the model itself. The SCLP allocates each demand point to one facility. Demand is not always allocated to the closest facility (Eberlan, 2004).

The original SCLP method was introduced by Torgeas et al.(1971). In our research, Drezner & Hamacher's formulation (2002) is used. A SCLP formulation can be stated as follows:

$$\text{MINIMIZE} \quad \sum_{j \in J} X_j \tag{2.1}$$

$$\text{Subject To} \quad \sum_{j \in Ni} X_j \geq 1 \qquad \forall i \in I \tag{2.2}$$

$$X_j \in \{0,1\} \qquad \forall j \in J \tag{2.3}$$

where:

I = the set of demand points indexed by i

J = the set of candidate points indexed by j

d_{ij} = the distance from each demand point i to each candidate site j

D_c = maximum distance coverage

N_i = {j | $d_{ij} \leq D_c$} = the set of all candidate sites j within the coverage distance D_c of demand point i;

$$X_j = \begin{cases} 1 & \text{if we locate at site j} \\ 0 & \text{if not} \end{cases}$$

The objective function (2.1) minimizes the number of selected facilities needed to cover each demand point. Constraint (2.2) ensures that each demand point is covered by at least one candidate site within D_c distance. Constraint (2.3) enforces the integrality nature of the decision variables.

2.4.2 Maximal Covering Location Problem-MCLP

In the SCLP method, we have no constraint on the number of facilities. On the other side, a standard MCLP method focuses on locating P facilities on network such that the maximal population is covered within a given distance. This given distance is often called the coverage radius. The coverage radius has a vital role and affects the optimal solution of the problem. The MCLP is commonly used to locate many service facilities such as schools, parks, hospitals and emergency units. The problem was first introduced by (Church & ReVelle, 1974) on a network and since then, various extensions to the original problem have been made. Normally, MCLP is preferred whenever there are insufficient resources or budget to cover the demand of all the nodes. Therefore, the decision maker determines a fixed budget/resource to cover the demands as much as possible (Davari, Zarandi, & Hemmati, 2011). The MCLP formulation is stated as follows:

MAXIMIZE $\sum_{i \in I} h_i Z_i$ (2.4)

Subject To $\sum_{j \in Ni} X_j - Z_i \geq 0 \quad \forall i \in I$ (2.5)

$$\sum_{j \in J} X_j = P \tag{2.6}$$

$$X_j \in \{0,1\} \qquad \forall j \in J \tag{2.7}$$

$$Z_i \in \{0,1\} \qquad \forall i \in I \tag{2.8}$$

where:

I = the set of demand points indexed by i

J = the set of candidate points indexed by j

h_i = demand value at demand point i

P = the limited number of facilities to locate

d_{ij} = the distance from each demand point i to each candidate site j

D_c = maximum distance coverage

$N_i = \{j \mid d_{ij} \leq D_c\}$ = the set of all candidate sites j within the coverage distance (D_c) of demand point i;

$$X_j = \begin{cases} 1 & \text{if we locate at site j} \\ 0 & \text{if not} \end{cases}$$

$$Z_i = \begin{cases} 1 & \text{if demand node i is covered} \\ 0 & \text{if not} \end{cases}$$

The objective function (2.4) is maximizing the sum of covered demand. Constraint (2.5) ensures that demand point *i* is not counted as covered unless we locate at one of the candidate points that covers node *i*. Constraint (2.6) limits the number of facilities to the given number. Constraints (2.7) and (2.8) force the decision variables to be binary (Drezner & Hamacher, 2002).

2.4.3 P-Median Location Problem

The p-median model, formulated by Hakimi in the mid-sixties (Hakimi, 1964), minimizes the total or average distance (or travel time) in a network where the nodes of the network are considered as the location candidates. This model assumes that the demand for service at each node and the travel times between nodes are deterministic (Serra & Marianov, 1998). In 1963, (Cooper, 1963) established the first step for p-median problems by developing a classic facility location problem on a plane to minimize costs with a heuristic approach. Since then, several algorithms have been developed for the p-median problem, including exact methods based on linear programming, constructive algorithms, dual based algorithms, and local search procedures. Hakimi formulated the problem for locating a single and multi-medians in 1964 (Sarikaya, 2009). The p-median problem does not only allow the application of location-allocation techniques to a greater number of circumstances, but it also reveals more efficient algorithms for solving location problems (Eberlan, 2004). Hence, the p-median model is mainly used to find the

location of p facilities while minimizing the demand weighted aggregate distance. This model is formulated as follows:

$$\text{MINIMIZE} \quad \sum_{i \in I} \sum_{j \in J} h_i d_{ij} Y_{ij} \tag{2.9}$$

$$\text{Subject To} \quad \sum_{j \in J} X_j = P \tag{2.10}$$

$$\sum_{j \in J} Y_{ij} = 1 \qquad \forall i \in I \tag{2.11}$$

$$Y_{ij} - X_j \leq 0 \qquad \forall i \in I, j \in J \tag{2.12}$$

$$X_j \in \{0,1\} \qquad \forall j \in J \tag{2.13}$$

$$Y_{ij} \in \{0,1\} \qquad \forall i \in I, j \in J \tag{2.14}$$

where:

I = the set of demand points indexed by i

J = the set of candidate points indexed by j

h_i = demand value at demand point i

P = the limited number of facilities to locate

d_{ij} = the distance from each demand point i to each candidate site j

$$X_j = \begin{cases} 1 & \text{if we locate at site j} \\ 0 & \text{if not} \end{cases}$$

$$Y_{ij} = \begin{cases} 1 & \text{if demand node i is assigned to a facility at node j} \\ 0 & \text{if not} \end{cases}$$

The objective function (2.9) minimizes the demand-weighted total distance traveled. Constraint (2.10) ensures that number of P facilities are located. Constraint (2.11) requires that each demand point be assigned to exactly one facility. Constraint (2.12) restricts the demand point assignments only if there is a facility at j. Constraints (2.13) and (2.14) force the decision variables to be binary. Constraint (2.14) also requires the demand point to be assigned to only one facility (Drezner & Hamacher, 2002).

Table 2 shows the basic relations among these three modeling types in terms of number of facilities, coverage ratio, and coverage distance.

Table 2. SCLP, MCLP, and P-Median Relationship

SCLP,MCLP, & P-MEDIAN RELATIONS (Daskin, 1995)			
	SCLP	**MCLP**	**P-MEDIAN**
Number of Facilities	Minimum "Objective Function"	EXOGENOUS	EXOGENOUS
% Demand Coverage	100%	Maximum "Objective Function"	100%
Coverage Distance	EXOGENOUS	EXOGENOUS	Minimum "Objective Function"

2.5 Solution Techniques

Heuristics and optimization are the two primary solution methods applied to location problems. A heuristic algorithm may not give the optimum result. Since the heuristic method gives a shorter solution time, large sized problems have been attempted to be solved usually with

heuristic methods by conceding the best solution (Sarikaya, 2009). There are three main heuristic methods; Greedy, Drop, and Interchange.

The Greedy Algorithm, developed by (Kuehn & Hamburger, 1963), presents an approach to locate facilities stepwise by least cost until *P* facilities are located. The Drop Algorithm, developed by (Feldman, Lehrer, & Ray, 1966), locates facilities to all candidate sites and then iteratively drops the facility that has the least effect on the objective function. The Interchange Algorithm, developed by (Teitz & Bart, 1968), selects *P* sites and then iteratively substitutes not included sites with each site and recalculates the objective function (Alkanat, 2008).

Researchers may prefer heuristic techniques when feasible and close to optimum solutions are required in a short time period. In the case of consuming too much time to find an optimum solution for a location problem, closeness to optimum solution may be a preferable trade off for a researcher.

The basic optimization method for large sized problems is mathematical programming. Linear programming, integer programming, non linear programming, and mixed integer-linear programming are the types of mathematical programming. Linear programming (LP) involves solving problems optimally by using linear objective functions and linear constraints. If the optimal values of the decision variables must be integer values, this is known as integer linear programming (Eberlan, 2004).

Location studies commonly use integer linear programming, since the decision variables are mostly integers. This kind of location problem can be solved by LP relaxation, branch and bound methods or by a linear solver program such as Excel Solver, LINDO, and LINGO.

2.6 Similar Location Problems

Location problems usually depend on similar algorithms since their basic problem is covering the demand points with the optimum number of facilities. Hence, there are many applications of location problems in social, commercial, industrial, and military research areas. Since our problem is a military resource dispatching problem, it is very usual to encounter similar studies which are based on allocating military facilities due to cost & resource constraints.

Toregas et al. present one of the earliest location studies about emergency facilities. They give an example of SCLP modeling by applying linear programming to locate emergency facilities with equal costs in the objective (Toregas, Swain, ReVelle, & Bergman, 1971). (Current & O'Kelly, 1992) report a modified version of the SCLP modeling with an application of locating two emergency warning siren types each of which has different cost and covering radius. They also emphasize that location modeling's results can be powerful and efficient tools in the design of such systems, and their use can lead to significant cost savings. Again as an emergency facility location problem, (Serra & Marianov, 1998) address the issue of locating fire stations in Barcelona with an approach of upgraded p-median modeling when there is uncertainty in demand, travel times or distance.

As one of the recent military applications of location problems, Eberlan et al. develop a model to optimally locate alert sites to cover areas of interest in the Continental United States (CONUS). His model finds the minimum number of alert sites, minimum aggregate network distance, and minimized maximum distance given a range of aircraft launch times and speeds with an integer programming method (Bell, Griffis, Cunningham, & Eberlan, 2011). (Dawson, Bell, & Weir, 2007) bring out a new approach, a combination of p-median and p-center models,

to provide solutions to the problem of locating security teams over a geographic area to maintain security for US Air Force Intercontinental Ballistic Missile Systems. This combined model supplies solutions that minimize the distances traveled while minimizing the maximum distance from any missile site to required security forces. (Overholts, Bell, & Arostegui, 2009) use a two-stage MCLP model to develop Inter Continental Ballistic Missile maintenance schedules for the US Air Force. By applying sensitivity analysis to the results of MCLP, they determine the impact of altering security response times and the number of security patrol areas on the quality of daily maintenance schedules and personnel usage.

In his study, (Alkanat, 2008) develops two location optimization models, SCLP and MCLP, to optimally locate SAM sites to defend specified areas of Turkish Air Space. One of his models finds the minimum number of SAM sites to cover the specified area; the other finds the maximum coverage for a given number of SAM sites. He reflects an analytical view of Turkey's long ranged SAM systems procurement process while comparing three types of SAM systems.

As another example of location study in the specialty of TUAF, in his research, (Sarikaya, 2009) provides optimal orbit locations for Turkish Airborne Early Warning and Control (AEW&C) aircraft in the combat arena. He examines three combat scenarios Turkey might encounter to cover and detect the threats as far as possible from Turkey within a defined risk level. The objective of his study is to define the number of needed AEW &C aircraft to obtain the full coverage of orbit locations with the help of MCLP.

2.6 Risk Value Generation Methods

Location optimization researchers have also studied about some weighing values to use in their formulations as demand values for demand points or as bonus values for candidate sites. Under the depths of this thought, there is an intention of affording some priority to more

demanded areas such as cost effective areas to locate facilities or winning customers to cover. Since we intend to enhance our demanded coverage of our TAs especially by the MCLP method, we need to generate some demand values of TAs. In terms of SAR operations, these demand values would probably be the risk level of the related TA to have an accident. Thus, a risk assessment study for TAs is generated to obtain values for using in our MCLP method. Chapter 3 explains our risk value generation methodology , but a short literature review is needed to justify our methodology.

2.6.1 Definition of Risk

Since risk is an everywhere issue, there have been many studies dedicated to understand the concept of risk analysis and assessment. Most of the risk studies are focused on the difference between uncertainty and risk at the beginning. While the uncertainty is defined as “indefinite, indeterminate and not known beyond a doubt”, risk is defined as “possibility of loss or injury; peril”. Uncertainty also can be stated as “unsureness about the future”. Whereby all the definitions about risk and uncertainty are depending on having unsure knowledge about the future, there is a strong relationship between the two terms. Risk can be accepted as a subset of uncertainty which means to have risk there should be some uncertain parameters or criteria about our future related decision. On the other side if there are some uncertain parameters or criteria about our decision, this does not mean that decision involves some risks (Kaplan & Garrick, 1981).

In their paper (Kaplan & Garrick, 1981) tried to make a quantitative definition of risk that fundamentally looks for the answer to the following three questions:

1. What can happen?

2. How likely is it that it will happen? and

3. If it does happen, what are the consequences?

As a result of trying to find a solution for these questions, risk can be defined as the combination of probability, consequence or evaluation measure, and measure of damage of that scenario. For the quantitative definition of risk, (Kaplan & Garrick, 1981) derive a function from the answers of these questions as (S_i, P_i, X_i) where S_i is a scenario identification or description; P_i is the probability of that scenario; and X_i is the consequence or evaluation measure of that scenario, i.e., the measure of damage.

2.6.2 Hierarchical Holographic Model (HHM)

HHM method is a particular form of diagram, which is particularly useful for the analysis of systems with multiple, interacting subsystems. The different columns in the diagram reflect different "perspectives" on the overall system. The HHM methodology recognizes that most organizational as well as technology-based systems are hierarchical in structure, and thus the risk assessment of such systems must be driven by and responsive to this structure. "Head topics" and "subtopics" are the two basic structural components of HHM. Where head topics are the major visions, concepts, and perspectives of success and subtopics provide a more detailed classification of the requirements for the success scenarios, or sources of risk for the risk scenarios (Haimes, 2009). The HHM approach will supply inputs for our risk matrices and we will use risk matrices to quantify the risk factors. A sample HMM illustrates subsystems of an aircraft development project in Figure 1.

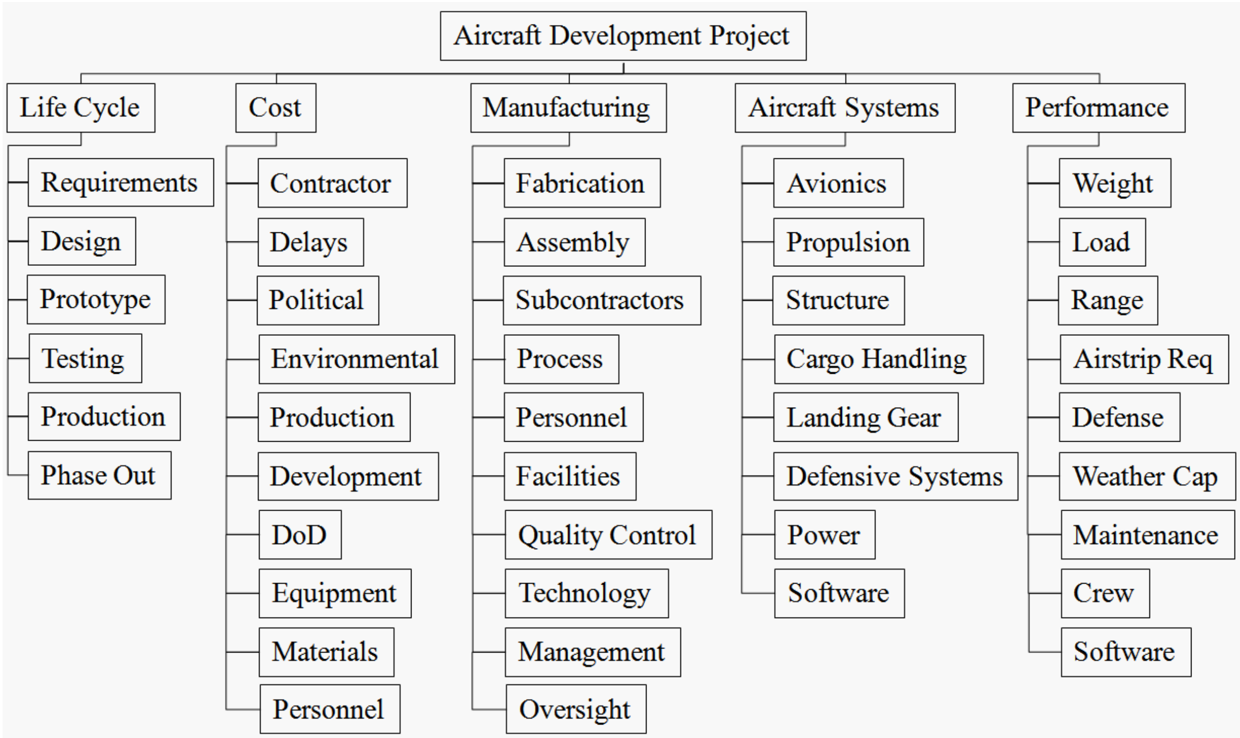

Figure 1. HHM Sample for Aircraft Development Project (Haimes, 2009)

2.6.3 Risk Matrices

Carrying out a risk analysis is hard due to its biased and qualitative nature. In risk analysis studies, risk matrices are commonly used tools. “A risk matrix is a table that has several categories of “probability,” “likelihood,” or “frequency” for its rows (or columns) and several categories of “severity,” “impact,” or “consequences” for its columns (or rows, respectively). It associates a recommended level of risk, urgency, priority, or management action with each row-column pair, that is, with each cell” (Cox, 2008). A risk matrix illustrates the level of threats for a system with a ranking order in terms of severity and the likelihood. The primary formulation for risk derived from a table (Figure 2) is Risk = Likelihood x Severity.

EXAMPLE OF A RISK MATRIX					
Severity / Likelihood	**No Safety Effect**	**Minor**	**Major**	**Hazardous**	**Catastrophic**
Frequent	G	Y	R	R	R
Probable	G	Y	R	R	R
Remote	G	G	Y	R	R
Extremely Remote	G	G	G	Y	R
Extremely Improbable	G	G	G	G	R

R : RED	HIGH RISK
Y : YELLOW	MEDIUM RISK
G : GREEN	LOW RISK

Figure 2. Example of a Basic Risk Matrix

2.7 Summary

In this chapter, after reviewing the history of location problems, parameters and types of location problems are described. Mathematical formulations of problem types used in this research are explained comprehensively. Solution techniques for these kinds of problems are discussed exhaustively as well. Research similar to our problem, especially those applied to military problem areas are presented. Additionally, since we use risk values to calculate demanded coverage in our MCLP modeling, a primary review for risk definition and some assessment methods are presented.

III. Methodology

3.1 Introduction

This chapter first states the problem and primary objectives of the research, and then presents the methodology to define parameters of the stated problem. Next, we discuss risk value generation for TAs to determine a weight for each TA to use in the MCLP method. Then we explain the quantification method for the risk values. Finally, we define changes to the models in Chapter 2 to make them applicable for our problem. All of these are then implemented using VBA (Visual Basic for Applications) & LINGO as a useful and flexible tool, which allows changing important parameters of the models easily.

3.2 Problem Description

As mentioned in the Chapter 1, TUAF has been researching about its optimum SAR units' locations. Even though a certain decision has not been made yet, a centralization idea of all SAR units and deploying them to the optimum points has become the most outstanding plan because of cost, training, logistics, and maintenance issues. Moving on from this point as an initiative approach and an effort to create an advisory document, this research aims to determine an optimum number of SAR units and their locations for TUAF in a deterministic methodology. Generating a location plan for TUAF SAR units while minimizing the number of DPs and total response time, and also maximizing the demanded coverage of TAs is the main purpose of this study.

3.3 Defining Objectives

This research's initial problem is to find the minimum SAR DPs for the given scenario to cover all demand points (i.e. fighter aircraft TAs) within a determined response time. Since it

effects the solution directly, the critical value is the given response time in this part of the problem. The SCLP method is used to determine the number of SAR DPs to cover all TAs.

The secondary problem is to cover as many TAs as we can with a given number of SAR DPs. The MCLP method is used to find the maximum coverage, which is a valuable objective under the constrained budget, number of assets, and personnel. Additionally a weighted demanded coverage of TAs is another aim of the research to extend our coverage in terms of demanded areas.

Subsequently, as a third problem, our research seeks to find a minimum average response time for the whole SAR system with a given number of SAR DPs which can be obtained by the first two models. The P-Median model is used to find the minimum average response time. The results of this part of the problem would be valuable if the decision makers prefer system's total response time instead of a limited response time for all TAs.

In summary, this research seeks answers for the questions stated below as our objectives:

- What is the minimum number of SAR DPs for a given scenario to cover all TAs?
- What are locations of SAR DPs for our case with a given number of DPs and a given response time to cover the maximum number of TAs?
- What are the locations of SAR DPs with a given number of DPs to obtain the minimum average response time of the whole system?

3.4 Parameter Selection

Similar to other location problems, the primary parameters are demand and candidate points in this research. These two parameters are used to generate the distance matrix, which is an

indispensible tool of a location problem. Even though our coding allows us to add or delete demand or candidate points, these parameters will be constant since the study is based on a notional scenario. After the selection of demand and candidate points, a distance matrix is generated with the help of an Excel formula. Response time and the number of SAR units are the variable parameters of models. These two parameters emerge as the input or the objective of the relevant model as shown in Table 2.

3.4.1 Demand Point Selection

Demand point is one of the basic two parameters of a location problem. In our study, demand points are defined as TAs of fighter aircraft. Since a TA is probably in a quadrilateral shape, utilization of a mathematical algorithm is needed to obtain some exact points with their coordinates. We preferred to use the centroids of quarters of a rectangular or square shaped TA instead of its corners as shown in Figure 3.

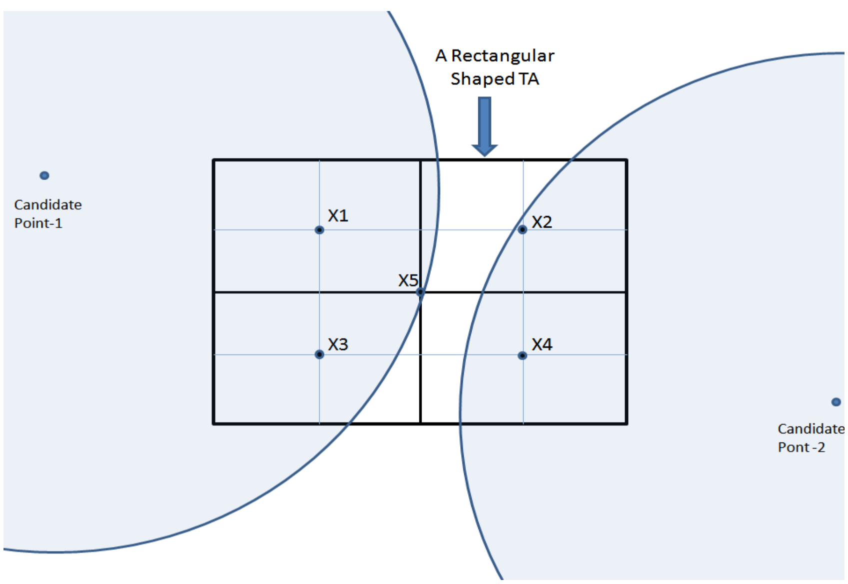

Figure 3. Demand Points of a Rectangular Shaped TA

The main idea of applying this methodology is to cover the maximum percentage of a TA area, especially for the ones, which are at the border of two candidate points coverage ranges. Defining only the corners of a TA as demand points may cause not covering an important area of a TA. That is why we preferred to use centroids without enhancing our number of demand points. Even though our models allow us to add as many number of TAs as we want, we intend to generate a practical decision matrix without compromising coverage area. Otherwise, we could easily take 20 intersection points shown in Figure 3 for each TA and generate about a thousand demand points. However, this kind of a methodology would presumably be tough in terms of application of models and interpretation of results.

Despite the fact that most of TAs are in a quadrilateral shape, a few of them are also in a trapezoid shape. We prefer to use the centroid methodology for these TAs as well as shown in Figure 4 to utilize the coverage area without enhancing the number of demand points.

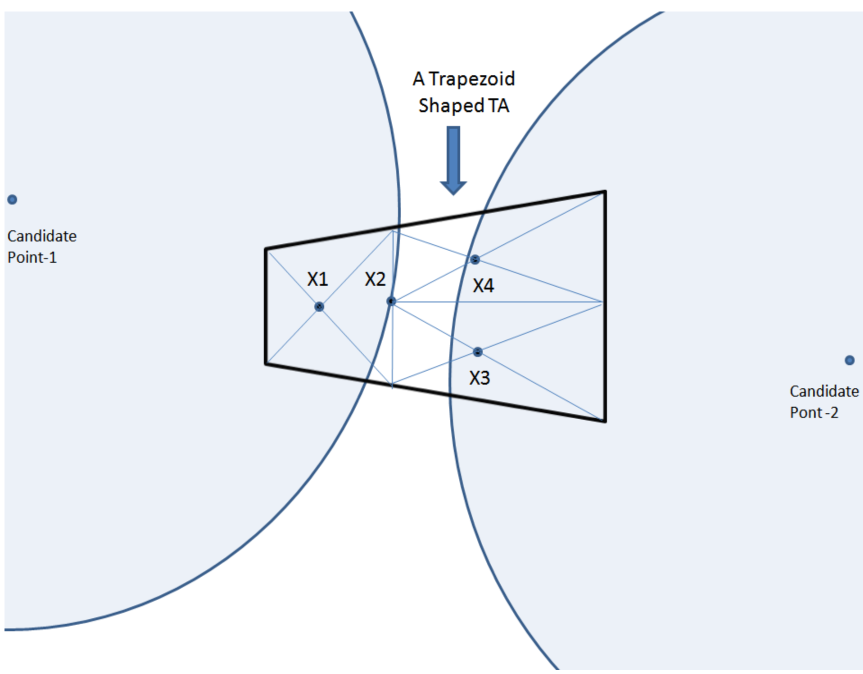

Figure 4. Demand Points of a Trapezoid Shaped TA

One can see that there is still some uncovered small areas in both shaped TAs. Even so, TAs at the borders of candidate points ranges constitute only a few percentage of TAs. Additionally, that uncovered distance can be stated by means of seconds in terms of helicopter flight. Hence, these few uncovered areas are accepted as negligible. Finally, 155 TA points are determined as demand points to be covered. The demand points are symbolized as “Y_i” in the mathematical models.

3.4.2 Candidate Point Selection

A candidate point is the other basic parameter of a location problem and it represents the area or point which is available to locate your facility. In our study, candidate points are defined as military or civilian-military shared airports, which are available to deploy our SAR units. All airports are assumed to have the same logistical, geographical and cost values. Thus, there is no prioritization for any airport in the applied models. The criteria about choosing the airports are availability to deploy, ability to supply basic fuel & maintenance services, having main facilities to meet basic vital needs of personnel, and being affordable for logistical support. These criteria led to eliminate some airports. In addition, it is confirmed that there are at least two candidate points in each region of Turkey. Finally, 25 airports are chosen as available DPs to deploy SAR units. The candidate points are symbolized as “X_j” in the mathematical models.

3.4.3 Generating Distance Matrix

The distance matrix is the basic tool for any discrete location problem. This matrix shows the distances from each demand point to each candidate point. Since our demand points are TAs and candidate points are DPs, our decision matrix shows the distances between each TA and DP matching.

Since it is a time consuming and not a flexible method to calculate each matching separately, a Excel formulation is used to calculate the distances to generate our distance matrix easily. Entering the geographic coordinates of TAs and DPs with the time format is enough to calculate the distance for the formulation shown at (3.1) (Chamberlain, 1996). Numbers at the end of the formula converts the grid format into a NM distance. The calculated distance by the formula is direct flight distance and the accuracy of the distances is crosschecked with the geographical programs such as Google Earth and Google Maps.

$$\begin{aligned} Distance_{ij} = cos^{-1}\Bigg(&\cos\Bigg(radians\Big(90 - Lat\left(Y_i\right)\Big)\Bigg) \\ &* cos\Bigg(radians\Big(90 - Lat\left(X_j\right)\Big)\Bigg) \\ &+ sin\Bigg(radians\Big(90 - Lat\left(Y_i\right)\Big)\Bigg) \\ &* \sin\Bigg(radians\Big(90 - Lat\left(X_j\right)\Big)\Bigg) \\ &* \cos\Bigg(radians\Big(Long\left(Y_i\right) - Long\left(X_j\right)\Big)\Bigg)\Bigg) * 3340.065 * 24 \end{aligned} \tag{3.1}$$

We could generate the distance matrix with the help of EXCEL and stated formula despite the numerous numbers of demand and candidate points. As a result, the distance matrix has emerged as shown in Table 3.

Table 3. Distance Matrix

	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Y11	Y12	Y13	Y14	Y15	Y16	Y17	Y18	Y19	Y20	Y21	Y22	Y23	Y24	Y25
X1	184.71	164.16	104.90	46.42	141.09	146.10	24.01	73.16	162.09	134.97	219.72	221.97	315.59	128.11	651.36	476.95	607.64	661.23	320.64	358.13	193.24	469.05	83.04	43.38	685.45
X2	181.11	170.99	110.89	54.63	149.73	155.71	23.04	67.95	171.94	126.04	229.57	229.42	306.12	119.41	642.42	469.01	599.74	653.21	312.96	352.58	196.09	462.47	85.67	51.18	677.00
X3	158.20	185.74	130.18	67.89	154.73	150.59	17.49	56.02	158.41	132.09	214.40	195.79	315.15	151.62	644.81	464.28	594.45	648.66	307.23	335.98	159.55	450.23	49.28	25.81	675.40
X4	159.27	184.67	131.49	69.31	150.63	143.33	30.23	64.09	148.70	142.53	204.00	183.13	325.46	164.27	653.27	470.91	600.79	655.18	313.85	338.82	151.01	454.45	42.25	17.36	682.76
X5	136.14	207.56	152.72	90.37	174.59	167.02	32.63	42.74	170.64	123.44	224.86	189.86	305.48	160.61	630.74	447.26	577.01	631.46	290.23	315.01	141.23	430.42	31.69	41.36	659.43
X6	140.59	204.46	147.53	85.84	174.73	170.71	21.18	35.87	177.48	113.73	232.87	204.12	296.61	145.74	624.95	444.05	574.22	628.43	287.00	316.84	155.10	430.43	46.40	45.13	655.23
X7	107.73	248.25	188.82	129.83	222.13	219.67	62.75	13.25	225.92	68.95	280.59	235.97	249.81	135.54	576.00	395.59	525.96	580.00	238.65	274.55	162.18	384.98	74.48	94.07	606.34
X8	119.82	230.12	171.47	111.37	202.69	199.68	43.97	6.98	206.11	86.67	261.06	222.22	268.81	137.70	595.98	415.36	545.64	599.75	258.36	291.56	157.50	403.43	59.84	74.08	626.29
X9	112.46	234.29	176.65	115.51	204.73	199.46	48.71	12.38	203.78	92.63	257.84	213.42	273.27	148.72	597.60	414.82	544.81	599.13	257.76	286.97	146.49	400.34	51.27	73.39	626.61
X10	133.47	235.36	174.43	119.69	214.54	217.38	57.96	31.14	228.46	62.43	284.86	254.53	245.13	107.72	578.30	403.93	534.68	588.09	248.11	293.10	188.42	399.56	92.32	96.29	612.00
X11	123.71	240.53	180.05	123.57	217.78	218.71	59.10	22.93	228.06	62.52	283.91	248.32	245.54	117.59	576.39	399.83	530.50	584.15	243.50	285.54	179.22	393.35	85.94	95.45	608.91
X12	360.66	163.08	189.18	199.90	126.03	95.90	247.16	289.22	76.62	367.03	27.94	178.91	550.04	353.41	877.45	689.88	817.86	872.88	533.87	539.81	274.66	661.45	239.95	209.24	903.82
X13	357.22	157.73	183.52	194.52	120.39	90.36	242.29	284.68	72.00	362.26	26.87	178.77	545.24	347.92	873.14	685.99	814.12	869.12	529.87	536.67	272.64	658.16	235.99	204.55	899.82
X14	366.03	170.25	196.96	207.53	133.75	103.68	254.27	295.93	83.55	374.00	31.70	180.10	557.04	361.12	883.87	695.77	823.56	878.61	539.91	544.77	278.24	666.59	246.00	216.15	909.84
X15	371.39	178.36	205.45	215.65	142.23	112.03	261.69	302.88	90.90	381.25	36.68	181.01	564.30	369.36	890.39	701.68	829.25	884.34	546.03	549.63	281.64	671.63	252.18	223.35	915.90
X16	362.34	175.19	199.94	208.26	137.18	105.42	253.36	294.22	82.62	372.76	27.64	173.32	555.82	362.23	881.53	692.67	820.21	875.30	537.05	540.58	272.87	662.58	243.24	214.86	906.91
X17	353.64	147.44	173.62	186.09	110.32	81.38	235.36	278.59	66.24	355.54	30.54	181.78	538.40	339.09	867.48	681.34	809.79	864.71	524.97	533.68	272.06	654.83	231.33	198.14	894.89
X18	350.38	142.12	167.96	180.79	104.67	75.93	230.62	274.20	62.26	350.87	32.40	182.12	533.66	333.63	863.22	677.54	806.12	861.02	521.07	530.67	270.36	651.64	227.60	193.63	890.96
X19	350.34	132.21	159.63	175.05	96.01	69.80	226.86	271.41	61.48	347.21	41.39	188.58	529.75	327.08	860.62	676.13	805.03	859.84	519.45	531.10	273.47	651.66	226.59	190.62	889.19
X20	352.38	128.18	157.06	174.21	93.26	69.01	227.11	272.15	63.65	347.46	46.49	193.15	529.82	325.65	861.37	677.48	806.52	861.28	520.71	533.32	276.87	653.69	228.24	191.31	890.35
X21	313.38	146.19	157.48	157.57	99.37	60.43	200.50	241.51	29.98	319.87	27.93	148.88	502.92	311.94	829.44	641.94	770.08	825.06	485.85	493.21	232.42	614.47	191.95	161.97	855.80
X142	458.00	776.46	715.27	659.89	752.94	747.25	593.52	543.29	745.44	484.72	792.71	683.71	348.34	574.39	167.59	140.60	32.64	67.08	293.05	285.30	563.26	163.32	580.22	621.78	122.77
X143	384.09	702.30	641.20	585.52	678.45	672.71	519.06	468.79	671.10	411.06	718.70	611.93	282.70	503.03	194.26	71.93	77.12	131.84	218.93	214.54	491.38	96.77	505.83	547.23	176.62
X144	403.47	716.79	655.46	600.77	694.31	689.77	534.76	484.83	689.22	424.49	737.63	633.41	287.40	513.07	168.92	79.30	55.10	110.40	233.73	237.27	512.88	121.71	523.83	563.96	152.11
X145	313.10	102.13	116.78	128.43	55.84	23.17	181.86	227.90	34.96	302.13	67.17	181.79	484.22	280.68	816.85	634.75	764.27	818.85	477.77	494.65	248.08	613.85	187.48	147.10	846.95
X146	271.46	92.28	77.70	76.07	42.49	29.43	130.97	178.73	56.87	250.78	111.70	183.76	432.30	229.37	766.44	586.94	716.99	771.29	429.87	452.80	223.38	570.05	145.46	98.97	798.05
X147	251.75	100.92	70.64	54.16	57.49	52.52	107.95	156.22	74.57	227.61	131.53	185.24	409.11	208.38	743.40	564.58	694.76	748.96	407.54	432.61	211.79	549.04	126.47	77.37	775.35
X148	262.42	119.28	105.84	92.35	67.65	34.88	135.56	179.26	36.27	255.69	94.03	155.18	438.57	246.53	768.46	584.74	714.05	768.71	427.87	444.01	202.73	563.14	136.78	98.51	797.39
X149	242.45	124.75	99.71	74.51	75.91	52.81	113.47	157.11	57.56	233.52	115.04	156.24	416.44	227.42	746.33	563.10	692.56	747.16	406.15	424.08	189.95	542.63	116.39	76.32	775.53
X150	224.88	124.45	83.88	43.20	84.09	76.47	83.43	130.28	89.93	203.75	147.65	176.93	386.14	194.51	718.59	538.42	668.47	722.76	381.35	405.68	189.91	522.16	99.94	50.59	749.65
X151	209.97	147.72	110.29	65.52	103.18	85.37	85.46	125.84	86.87	203.93	142.54	152.09	386.98	208.90	714.78	530.59	659.94	714.58	373.71	391.57	165.14	509.90	83.82	46.07	743.26
X152	404.09	113.03	163.95	201.85	106.98	108.87	264.07	312.94	122.87	382.08	111.46	259.97	560.79	340.90	898.48	721.32	851.48	905.70	564.28	585.73	338.87	704.02	278.02	233.55	931.80
X153	203.21	253.84	228.34	184.28	202.55	166.36	174.07	185.07	136.27	262.82	156.71	40.72	434.07	308.16	733.25	534.77	657.58	712.86	385.53	369.86	93.35	492.90	121.71	141.02	749.57
X154	195.51	277.53	250.14	203.47	226.46	190.66	186.80	191.71	160.66	266.55	179.17	43.42	432.69	320.07	724.48	524.14	645.21	700.43	377.54	355.75	77.62	478.69	129.80	156.75	738.47
X155	210.47	285.99	261.49	216.95	234.42	197.16	202.91	208.70	164.99	283.56	177.97	31.68	449.06	336.45	738.52	537.41	657.51	712.68	392.07	367.27	89.86	490.00	146.62	171.88	751.42

3.4.4 Defining Response Time

Response time is the required time to pass from a DP to a defined TA including the quick reaction time of a SAR unit. Since our distance matrix is calculated in terms of distances, we need to apply a basic formula including assumed SAR unit reaction and helicopter speed to convert the response time into a distance to use as an input to our models as

$$D_c = \text{(Required Response Time in Minutes-15) / 60) * 130)}, \qquad (3.2)$$

where, 15 is the Quick Reaction Time of SAR units, 60 converts the time for flight in terms of hours, and 130 is the assumed helicopter speed in NM per hour. Hence, this formulation makes it possible to enter the DM's asked response time value as a coverage distance input for our models.

3.4.5 Defining Number of SAR Units

An Air Force SAR unit should possess a helicopter, pilots, technicians, and SAR specialist commandos. At the same time, it is necessary to ensure the continuity of training for these personnel. Hence, there are many restricting factors of capabilities to deploy many SAR units. For this reason, acquiring the maximum utilization with the minimum number of SAR has become our primary criterion.

This research aims to find the minimum number of SAR units to cover all TAs. This number changes according to the asked response time as a matter of course. Especially for reasonable response times, like 60-90 minutes, the needed SAR units are to be between six and nine. In addition, we demand to see the results for fewer numbers in case of higher response times. Therefore, this research examines the number of SAR units as an input or a constraint of our models between the numbers of 2 and 10.

3.5 Risk Value Generation for Weighed MCLP Method

Military flights are always accepted as one of the highest risk containing missions of a military. Since they are risky missions, most of the countries' military structure includes SAR assets to rescue the flight crew in case of an accident or an ejection. For the MCLP model weighed coverage method, the risk level of a military flight can be admissible as a demand value of the TA in which flight is executed. Therefore making a risk assessment of Turkey within a

sectored approach in terms of risk levels of military flights and survival of a crew appears to be a rational methodology to supply weigh values for MCLP method.

To obtain these values, this research first generates an appropriate HHM model to expose the risk factors of a military flight. Then, it presents a risk matrix application to quantify the importance of each risk factor and to choose the most effective factors. Subsequently it assigns risk values with the help of Subject Matter Experts (SMEs) for each defined sector in terms of the most important risk factors. Finally, it assigns risk values to TAs according to their existing sector.

3.5.1 HHM Generation

Generating a similar model to HHM shown at Figure 1 helps us to define risk factors of a flight at the first step of this phase. The generated HHM, Figure 5, divides the risk factors set into two subsets as “Risks During Flight” and “Risks After Ejection”. This division is the result of our goal that wants to evaluate risks in terms of SAR operations. Since military flights safety is mostly dependant on meteorological conditions and meteorology affects not only the flights but also the SAR operations effectiveness, this HHM accepts meteorology as an important sub risk for two cases. Furthermore air traffic density, coordination problems with other air traffic, risky mission types mostly flown in a specific region, and the hazards crew may face after ejection are other identified subsets of our military flights risk set. These subsets are also detailed to cover all risk factors that may appear.

Risk Factors of a Military Flight

DURING FLIHGT
* METEOROLGY
Cloudiness
Fog
Turbulences
Tunderstorms
Bird Mitigation Ways

* AIR TRAFFIC DENSITY
Central Areas
Over Numbers of Flight
Touristic Areas (fun flights)
Night Flight Density

* COORDINATION
Multinational/Joint Exercises
Coordination with Civillian Traffic

* MISSION & AIRCRAFT TYPES
Air to Air Missions
HVAA's Areas
Training Flights

AFTER EJECTION
* TERRAIN
Sea
Rocky
Broken
Silvan

* METEOROLGY
Cloudiness
Temprature / Altitude
High Winds
Night Conditions

* POLITICAL
Hazardous Areas
International Seas
Borders

Figure 5. Risk Factors of a Military Flight

3.5.2 Risk Value Quantification

(Haimes, 2009) represents a methodology to apply a Risk Filtering Ranking & Management (RFRM) method to reduce the number of risk factors in a HHM. This methodology defines 8 phases for RFRM. After generating the HHM, this research uses the “Multicriteria Evaluation” phase of RFRM methodology that checks the system in terms of redundancy, resiliency, and robustness to eliminate the ineffective and qualitative risk factors. Then, it makes use of “Quantitative Ranking” phase to obtain quantitative values by means of applying risk matrixes. Our SME’s experiences are referred throughout this process.

Since we have many factors in the format shown at Figure 5, an application of a "Multicriteria Evaluation" is needed to eliminate some of the risk factors duplicated in both parts and having too low a risk level. The final risk factors are shown in Figure 6 after RFRM application.

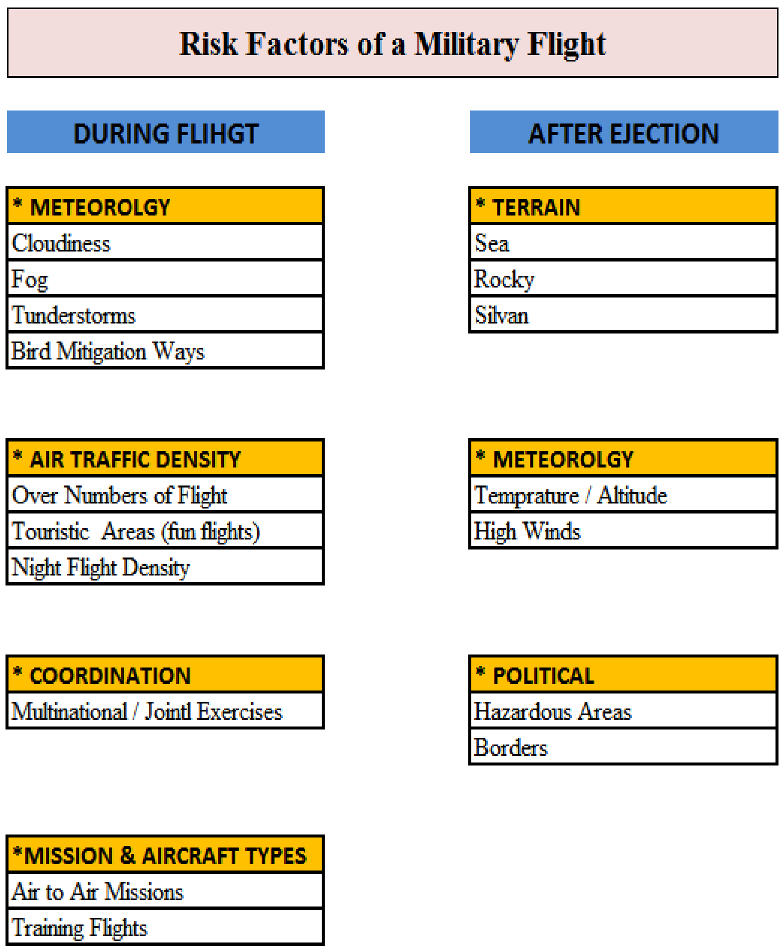

Figure 6. Filtered Risk Factors of a Military Flight

After reducing the number of risk factors, the basic problem is making up some quantitative values for these factors. The research generates values by creating seasonal risk matrixes. The reason for forming matrixes by seasons is the very large effect of meteorological conditions on flight accidents. Our SME's are asked to fill out the seasonal matrixes with the appropriate

factors according to their fighter flight experience in Turkish Air Space. The results of their inputs are shown at Figure 7, Figure 8, Figure 9, and Figure 10.

FALL (15 Sept-15 Dec)					
Likelihood/ Effect	**Unlikely**	**Seldom**	**Occasional**	**Likely**	**Frequent**
Catastrophic	* Hazardous Areas				
Critical			*Tunderstorms *Over Numbers of Flight	*Night Flight Density *Multinationa/Joint Exercises	* Training Flights * Sea
Serious		*Rocky * Silvan	* Borders * Fog	*Birds Immigration * Air to Air Missions	*Cloudiness
Moderate		* Touristic Areas/ Fun Flights		* Temprature / Altitude * High Winds	
Marginal					

Figure 7. Evaluated Risk Matrix for FALL Season

WINTER (15 Dec-15 Mar)					
Likelihood/ Effect	**Unlikely**	**Seldom**	**Occasional**	**Likely**	**Frequent**
Catastrophic		* Hazardous Areas			* Sea
Critical	*Over Numbers of Flight * Multinationa/Joint Exercises	*Night Flight Density * Rocky * Silvan	* Borders * Training Flights	*Tunderstorms * Temprature / Altitude	*Cloudiness
Serious		*Fog *Birds Immigration	* Night Flight Density	* Air to Air Missions	
Moderate	* Touristic Areas/ Fun Flights			* High Winds	
Marginal					

Figure 8. Evaluated Risk Matrix for WINTER Season

SPRING (15 Mar- 15 Jun)					
Likelihood/ Effect	Unlikely	Seldom	Occasional	Likely	Frequent
Catastrophic		* Hazardous Areas			
Critical			*Tunderstorms *Over Numbers of Flight	* Night Flight Density * Multinationa/Joint Exercises	* Training Flights * Sea
Serious		* Rocky * Silvan	* Borders * Fog * Birds Immigration	* Air to Air Missions * Cloudiness	
Moderate		* Touristic Areas/Fun Flights		* Temprature / Altitude * High Winds	
Marginal					

Figure 9. Evaluated Risk Matrix for SPRING Season

SUMMER (15 Jun - 15 Sep)					
Likelihood/ Effect	Unlikely	Seldom	Occasional	Likely	Frequent
Catastrophic	* Hazardous Areas				
Critical			* Night Flight Density *Over Numbers of Flight	* Multinationa/Joint Exercises	* Training Flights
Serious		* Rocky * Silvan * Tunderstorms	* Fog * Birds Immigration * Borders	* Air to Air Missions * Cloudiness	
Moderate			* High Winds	* Temprature / Altitude * Touristic Areas/Fun Flights	
Marginal					* Sea

Figure 10. Evaluated Risk Matrix for SUMMER Season

Subsequent to forming risk matrixes, the rank reciprocal rule (Winterfeldt & Edwards, 1986) which defines the weight for the i^{th} attribute is applied to select the most risky factors. The formulation defined for rank reciprocal rule is "$W_i = \frac{1/R_i}{\sum_i 1/R_i}$" where i is 1,2,3,4 to symbolize the colors in the risk matrix. The values and the weighing formulation obtained from the rank reciprocal rule is shown at Figure 11.

	Ri	1 / Ri	Weight	
Red	1	1	4.8	1
Orange	2	0.5	2.4	1
Yellow	3	0.33333	1.6	1
Green	4	0.25	1.2	1
		2.08333		10
Value = 4.8R+2.4O+1.6Y+1.2G				

Figure 11. Rank Reciprocal Application for Risk Matrixes

This method revealed to obtain formula Value = 4.8R+2.4O+1.6Y+1.2G. Where the count of the number times a risk factors shows up in a seasonal matrix is multiplied by the weights found using the rank reciprocal method. The final values for each risk factor are shown in Figure 12.

DURING FLIHGT							
* METEOROLGY		* AIR TRAFFIC DENSITY		* COORDINATION		*MISSION & AIRCRAFT TYPES	
Cloudiness	14.4	Over Numbers of Flight	9.6	Multinational / Joint Exercises	9.6	Air to Air Missions	9.6
Fog	6.4	Touristic Areas (fun flights)	5.2			Training Flights	16.8
Tunderstorms	8.8						
Bird Immigration Ways	7.2						
Night Flight Density	9.6						

AFTER EJECTION					
* TERRAIN		* METEOROLGY		* POLITICAL	
Sea	16	Temprature / Altitude	7.2	Hazardous Areas	19.2
Rocky	7.2	High Winds	6.4	Borders	7.2
Forest	7.2				

Figure 12. Weighing Values for Each Risk Factor

After reaching these values, the ones below 9.6 are eliminated because the ones higher than or equal to 9.6 refers to an average of orange or red color, which can be defined as a remarkable risk factor. Finally, the most probable and severe 8 risk factors appear to be risk factors to evaluate our sectors of Turkish Air Space in terms of military flights.

At this phase, our SME’s are asked to evaluate the sectors (Figure 13) in terms of determined risk factors. A value focus thinking method applied with the help of the meteorological data and our SME’s experiences about the Turkish Air Space. SMEs gave a value from 1 to 10 for each sector - risk factor matching. The results of their evaluation are shown in Table 4.

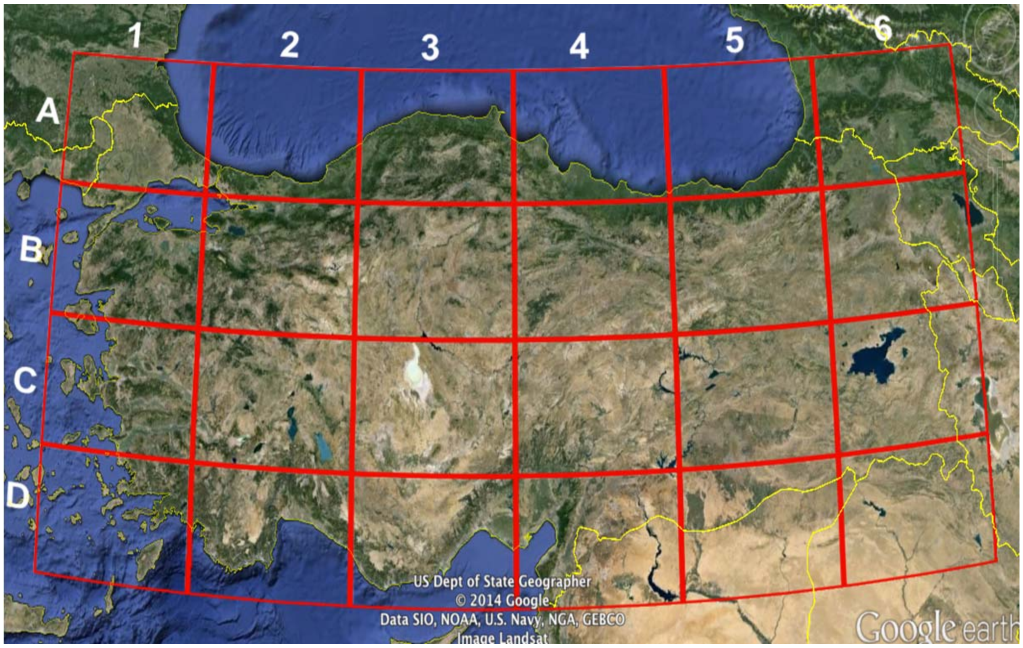

Figure 13. Defined Sectors of Turkish Air Space

Table 4. Evaluation of Turkish Air Space Sectors

	1	2	3	4	5	6
A	33	41	42	44	38	21
B	52	49	52	46	33	25
C	49	46	51	44	53	46
D	32	28	30	45	39	28

According to their evaluations, the most hazardous sectors are B1, B3, C3 and C5 in terms of military flights. These obtained values will be used as weighting values of TAs in our MCLP model. TAs weighting values are assigned according to the sector they exist in.

3.6 Solution Technique Applications for Research

This research presents a mathematical optimization technique to obtain optimum solutions. Since most of the similar location problems in related literature are figured out as integer programming, our preference for our mathematical optimization models is integer programming. This research presents an application of SCLP, MCLP, and P-median models which are appropriate for our objectives. All these specific models are applied as integer codes due to no need for fractional results.

3.6.1 Application Technique for SCLP Model

This research's first objective is to find the minimum SAR DPs to cover all demand points (i.e. fighter aircraft TAs). The SCLP method determines the minimum number of SAR DPs to cover all TAs within a determined response time. With a basic formulation as in Chapter 2, LINGO gives unfeasible solutions if there is no smaller distance than the required one for a TA to any DP (i.e. if the N_i is a null set).

The used formulation is:

MINIMIZE $$\sum_{j \in J} X_j \tag{3.3}$$

Subject To $$\sum_{j \in Ni} X_j \geq 1 \qquad \forall i \in I,\ N_i \neq \varnothing \tag{3.4}$$

$$X_j \in \{0,1\} \qquad \forall j \in J \tag{3.5}$$

$$X_1 = 1 \tag{3.6}$$

where:

I = the set of TAs indexed by i

J = the set of DPs indexed by j

d_{ij} = the distance from each TA i to each DP j

D_c = required distance

$N_i = \{ j \mid d_{ij} \leq D_c \}$ = the set of all DPs j within the required distance D_c of TA i;

$$X_j = \begin{cases} 1 & \text{if we locate at DP j} \\ 0 & \text{if not} \end{cases}$$

The objective function (3.3) minimizes the number of selected DPs needed to cover all TAs. Constraint (3.4) ensures that each TA is covered by at least one DP within D_c distance. Constraint (3.5) enforces the integrality nature of decision variables. Constraint (3.6) ensures that X_1 is assigned as a DP since an on duty SAR unit always exists at our central SAR base according to our scenario.

3.6.2 Application Technique for MCLP Model

Another objective of this research is to cover as many TAs as we can with a given number of DPs. The MCLP method is a useful application to obtain maximum coverage with a limited number of DPs. Furthermore, it is also an applicable model to reach the maximum demanded coverage of TAs by using risk values as demand weights.

This research's applied MCLP formulation can be stated as follows:

$$\text{MAXIMIZE} \quad \sum_{i \in I} r_i Y_i \tag{3.7}$$

Subject to $$Y_i - \sum_{j \in Ni} X_j \leq 0 \qquad \forall i \in I \tag{3.8}$$

$$\sum_{j \in J} X_j \leq P \tag{3.9}$$

$$X_j \in \{0,1\} \qquad \forall j \in J \tag{3.10}$$

$$Y_i \in \{0,1\} \qquad \forall i \in I \tag{3.11}$$

$$X_1 = 1 \tag{3.12}$$

where:

I = the set of TAs indexed by i

J = the set of DPs indexed by j

r_i = risk value at TA i

P = the limited number of DPs

d_{ij} = the distance from TA i to each DP j

D_c = required distance

$N_i = \{j \mid d_{ij} \leq D_c\}$ = the set of all DPs j within the required distance (D_c) of TA i;

$$X_j = \begin{cases} 1 & \text{if we locate at DP j} \\ 0 & \text{if not} \end{cases}$$

$$Y_i = \begin{cases} 1 & \text{if TA i is covered} \\ 0 & \text{if not} \end{cases}$$

The objective function (3.7) maximizes the demanded coverage of TAs. Constraint (3.8) enforces a TA *i* to be covered (i.e. $Y_i = 1$ if we locate at one of the DPs that covers TA *i*). Constraint (3.9) limits the number of DPs to the given number. Constraints (3.10) and (3.11) force the decision variables to be binary. Constraint (3.12) ensures that X_1 is assigned as a DP since an on duty SAR unit always exists at our central SAR base.

3.6.3 Application Technique for P-Median Model

Another objective of this research is minimizing the total or average response time of SAR system within a given number of SAR DPs. We present a formulation to reach the minimum aggregate distance value for the whole SAR system. However, this formulation does not guarantee that it minimizes the maximum distance for each TA from its closest facility, which is actually the problem area of P-center model.

This research's applied P-median formulation is stated as follows:

MINIMIZE $$\sum_{i \in I} \sum_{j \in J} d_{ij} Y_{ij} \tag{3.13}$$

Subject To $$\sum_{j \in J} Y_{ij} = 1 \qquad \forall i \in I \tag{3.14}$$

$$MX_j - \sum_{i \in I} Y_{ij} \geq 0 \qquad \forall j \in J \tag{3.15}$$

$$\sum_{j \in J} X_j = P \tag{3.16}$$

$$X_j \in \{0,1\} \qquad \forall j \in J \tag{3.17}$$

$$Y_{ij} \in \{0,1\} \qquad \forall i \in I, j \in J \tag{3.18}$$

$$X_1 = 1 \tag{3.19}$$

where:

I = the set of TAs indexed by i

J = the set of DPs indexed by j

P = the limited number of DPs

d_{ij} = the distance from each TA i to each DP j

$$X_j = \begin{cases} 1 & \text{if we locate at DP j} \\ 0 & \text{if not} \end{cases}$$

$$Y_{ij} = \begin{cases} 1 & \text{if TA i is assigned to a DP j} \\ 0 & \text{if not} \end{cases}$$

The objective function (3.13) minimizes the total distance traveled in the whole SAR system. Constraint (3.14) enforces that each TA is assigned to exactly one DP. Constraint (3.15) enforces that X_j=1 when one or more than one TA is covered by an assigned DP j. X_j is used as a counter variable here to limit the number of DPs in the follow on constraint. Constraint (3.16) limits the number of assigned DPs to a given number P. Constraints (3.17) and (3.18) force the decision variables to be binary. Constraint (3.19) ensures that X_1 is assigned as a DP since an on duty SAR unit always exists at our central SAR base.

3.7 Generating VBA & Lingo Combination as a Useful Tool

In Linear Integer Programming methodology, LINGO is a very appropriate and commonly used program. It can easily solve large optimization problems, which have many variables and restrictions. However, it may be time consuming to change these variables and constraints for

each studied scenario. Therefore, we generated a user friendly VBA & LINGO interface to change each exogenous variable stated in Table 2 and to get the solutions in a quick and easy readable format. Finally, this interface provides an easy application of three models – SCLP, MCLP, & P Median – for all basic location problems after inputting the coordinate data of demand and candidate points. It consists of EXCEL, which exists almost in every computer and LINGO, a common integer-programming tool today. That is why it appears to be a very useful interface.

3.7.1 Easy Method to Change Parameters

In this research, one of the intentions is being flexible about variables. Required response time, coverage distance, and number of SAR DPs are exogenous variables of this study. A handy VBA code is generated to easily change these variables to have results for very short intervals of variable values.

Additionally, our problem has 155 by 25 distance matrix which means 3875 distance variables total. It is possible to add or delete both TAs and DPs into our models as well. Hence, our VBA code provides an ability to change our distance matrix (Table 3) and parameters in seconds.

3.7.2 Logic of VBA & LINGO Interface

Since we have so many variables, objective functions and constraints of the models are very challenging to figure out. Our VBA code figures out the model formulations by using distance matrix and multiplier cells like risk values while referring to our applied mathematical models. After figuring out these functions, it writes them into a LINGO file and makes LINGO solve the problem. Then, it gets solutions from LINGO and writes them into an Excel file. In addition, it

finds valuable results from the solution pages. A result of the SCLP model is shown at Figure 14 as an example of readable solution.

Defined Distance: 130
of Assigned DP's : 9
Assigned DP's Names : Y1, Y8, Y9, Y10, Y13, Y16, Y17, Y19, Y21
of Uncovered TA's : 5
Uncovered TA's Names: X66, X67, X69, X106, X108

Figure 14. Example of SCLP Model Solution

Figure 14 shows the result of the SCLP model for 130 NM distance (i.e. 75 minutes response time). One can easily see that it is not possible to cover all TAs within our given required response time. Additionally the assigned DPs names and uncovered TA names can easily be observed. Due to some classification issues, the demonstrations of names with X and Ys is required. In our given scenario, every X and Y reflects to a real name of TA and DP.

3.8 Summary

In this chapter, the methodology of this research is explained comprehensively. The objectives, parameters, and the methods for defining parameters of the research are presented extensively. Subsequently risk value generation for the MCLP model is described to fully express the quantification methodology of risk values. Since we did some additions or transformations to the models in literature, our methodology about the applications is described with all details. Finally, some short descriptions are given about our VBA & LINGO interface, which can be accepted as a useful tool for basic location problems. Chapter 4 interprets the results obtained by this interface.

IV. Results and Analysis

4.1 Introduction

This chapter presents results for three applied models that are SCLP, MCLP, and P-median. After applying the mathematical models in Chapter 3, the results obtained from the VBA & LINGO interface are interpreted.

The primary considerations to evaluate the results are response time, number of covered TAs, and number of assigned DPs. Response time is defined in 5-minute. After defining the minimum number of DPs with the help of the SCLP model, the number of DPs is used as an input for the MCLP and P-Median models to define the optimum locations points. The number of DPs start at 3 and goes to the maximum number obtained from the SCLP model increasing by 1. The aim of this analysis is to show the effect of each additional DP and each 5-minute increase in response time. The impact of TAs risk values are shown by the MCLP model while maximizing the demanded coverage with a limited number of DPs. Then, this chapter presents the optimum locations of SAR units with the help of the P-Median model which minimizes the aggregate distance (response time) of the system.

The results of the three applied models are all illustrated and are a beneficial reference for TUAF to decide the locations of SAR DPs.

4.2 Solutions

All SCLP, MCLP, and P-Median model results are shown separately. The solution charts are figured out with the help of our VBA & LINGO interface that gives easy readable results.

4.2.1 Solutions for SCLP Model

The SCLP model essentially searches for the number of SAR DPs to cover all TAs. However, there is a little issue that some TAs cannot be covered with any DP if the required response time is too short. Therefore, as mentioned in the Chapter 3, we can easily observe the number of uncovered TAs and their names through our coding. Thus, coding allows us to determine problem TAs which are far away from every DP. The results for SCLP model are presented at Table 5.

Table 5. Results of SCLP Model

Required Response Time (Min)	# of Assigned DP's	# of Uncovered TA's	# of Covered TA's	Names of Uncovered TA's
45	14	40	115	X43, X44, X47, X50, X51, X62, X65, X68, X85, X86, X87, X88, X89, X91, X92, X93, X94, X96, X98, X103, X104, X105, X106, X107, X108, X109, X110, X111, X116, X117, X118, X119, X121, X122, X125, X126, X133, X134, X143, X152
50	14	26	129	X65, X68, X85, X86, X87, X88, X89, X91, X92, X93, X96, X98, X103, X104, X105, X106, X107, X108, X109, X110, X111, X116, X118, X119, X121, X152
55	12	18	137	X86, X87, X88, X89, X92, X93, X98, X103, X104, X105, X106, X107, X108, X109, X110, X111, X116, X152
60	9	12	143	X88, X89, X92, X103, X104, X105, X106, X107, X108, X109, X111, X152
65	8	6	149	X92, X103, X104, X106, X108, X109
70	7	4	151	X104, X106, X108, X109
75	7	2	153	X106, X108
80	7	0	155	
85	6	0	155	
90	6	0	155	
95	5	0	155	
100	4	0	155	
105	3	0	155	
110	3	0	155	
115	3	0	155	
120	3	0	155	

As can be seen at Table 5, many uncovered TAs exist for the response time values less than 80 minutes. Especially the TAs X_{92}, X_{103}, X_{104}, X_{106}, X_{108}, X_{109} exist consistently for all cases less than 70-minute response time. When their position is checked in our scenario, it is observed that these TAs are the further quad or half part of four training areas at the northeast and southwest edge of scenario map. Rearranging the position of these TAs may be a valuable trade-off for decision makers to gain 15 minutes in terms of response time. Determining the SAR system's response time as 65-minute instead of 80 would presumably be a distinctive utilization of the system.

Figure 15 presents a comparison chart for the response time and coverage parameters.

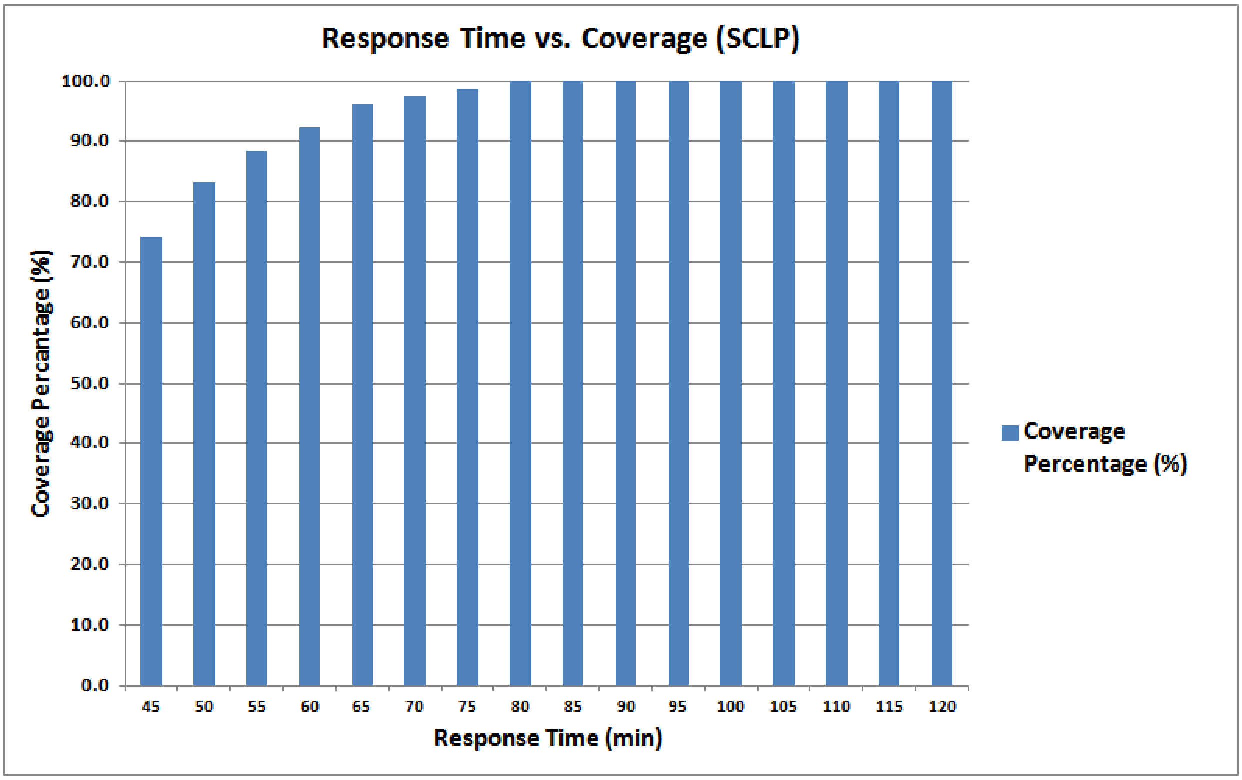

Figure 15. Response Time vs. Coverage Chart (SCLP)

The very first observation can be taken from Figure 15 is that it is not possible for the given scenario to cover all TAs within a range less than 80 minutes. However, since 6 TAs are uncovered for 65-minute response time case, it can be possible to obtain full coverage by making little adjustments on the TA map. Repositioning or scrolling the problem TAs mentioned above through inland may be a wise course of action to decrease the SAR system's response time definition for 15 minutes. If a lessening to 60 minutes is demanded, 12 TAs should be repositioned which may not be accepted as worth a 5-minute gain in response time.

After pointing out the effect of changes in response time parameter, a comparison for number of required DPs and response time is illustrated at Figure 16. This comparison introduces the results for the actual aim of SCLP method, determining the required number of DPs to cover all TAs.

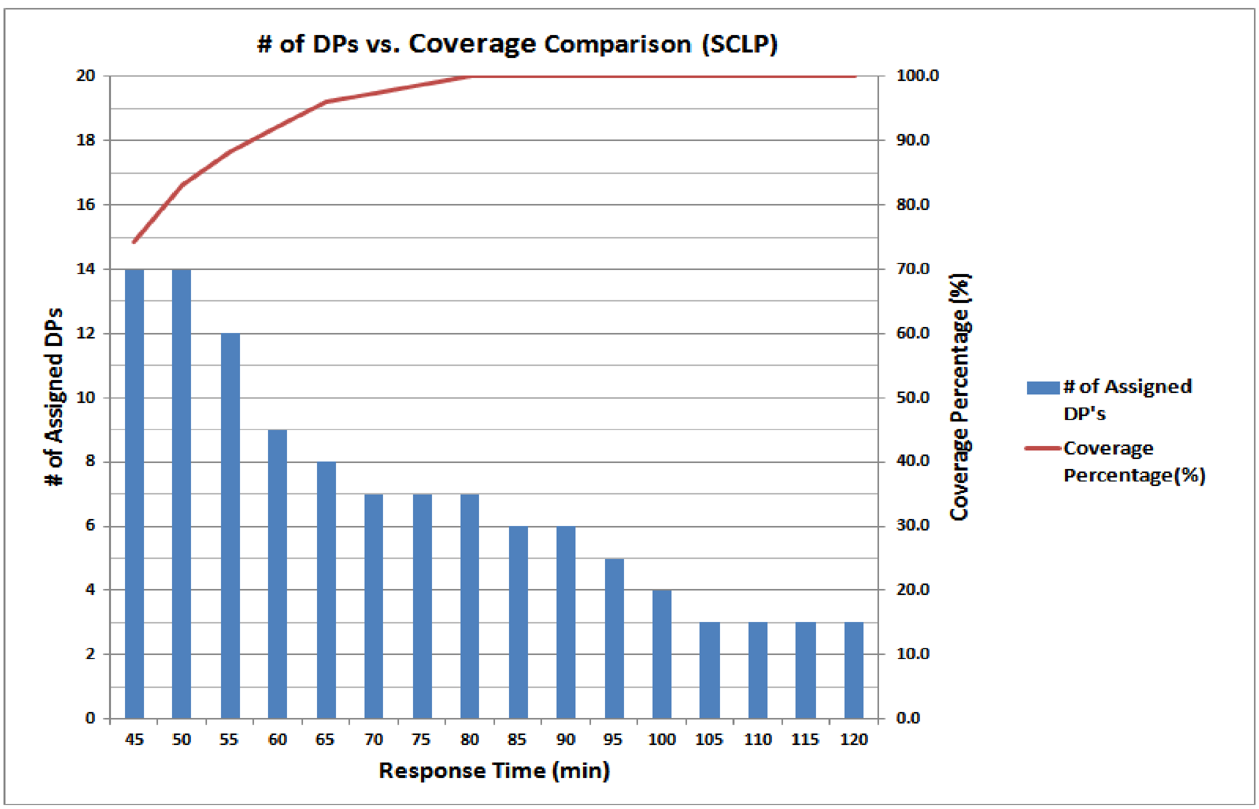

Figure 16. # of DPs vs. Coverage Chart (SCLP)

Figure 16 gives the critical solution that we need at least 7 DPs to cover all TAs within a defined 80-minute response time. Even though we enhance the number of DPs, it does not seem possible for our scenario to cover all TAs less than 80-minute cases. However, making minor arrangements on the TA map may result to cover all TAs within a 65-minute response time with 8 SAR DPs. The required number of DPs reduces in case of higher required response times inherently. The required number decreases linearly from 9 to 3 at 105-minute and then remains constant for the higher values of response time.

Table 6 presents the assigned DPs' names from the SCLP model for the values of 3 to 9 DPs and 60 to 105-minute response time interval.

Table 6. Assigned DPs by SCLP Model

Required Response Time (Min)	# of Assigned DP's	Names of Assigned DPs
60	9	Y4, Y6, Y10, Y11, Y12, Y13, Y16, Y17, Y18
65	8	Y4, Y5, Y9, Y10, Y12, Y13, Y16, Y18
70	7	Y6, Y10, Y12, Y13, Y16, Y17, Y24
75	7	Y4, Y9, Y10, Y12, Y13, Y16, Y17
80	7	Y9, Y10, Y12, Y13, Y15, Y16, Y24
85	6	Y6, Y8, Y12, Y13, Y15, Y16
90	6	Y7, Y9, Y12, Y13, Y16, Y17
95	5	Y7, Y9, Y13, Y16, Y17
100	4	Y9, Y13, Y17, Y24
105	3	Y9, Y13, Y17

At this point, we remind the reader that Y_1 is already assigned by LINGO for all options since we force it to be assigned in our mathematical models. Hence, Y_1 is not stated in all solution charts. Y_{13} appears to be an indispensible DP to cover all TAs according to results. Its no replacement statue on the north side of our map makes it an element of every solution set.

Due to its existence in every solution set, a sensitivity analysis is executed for Y_{13} as shown at Figure 17.

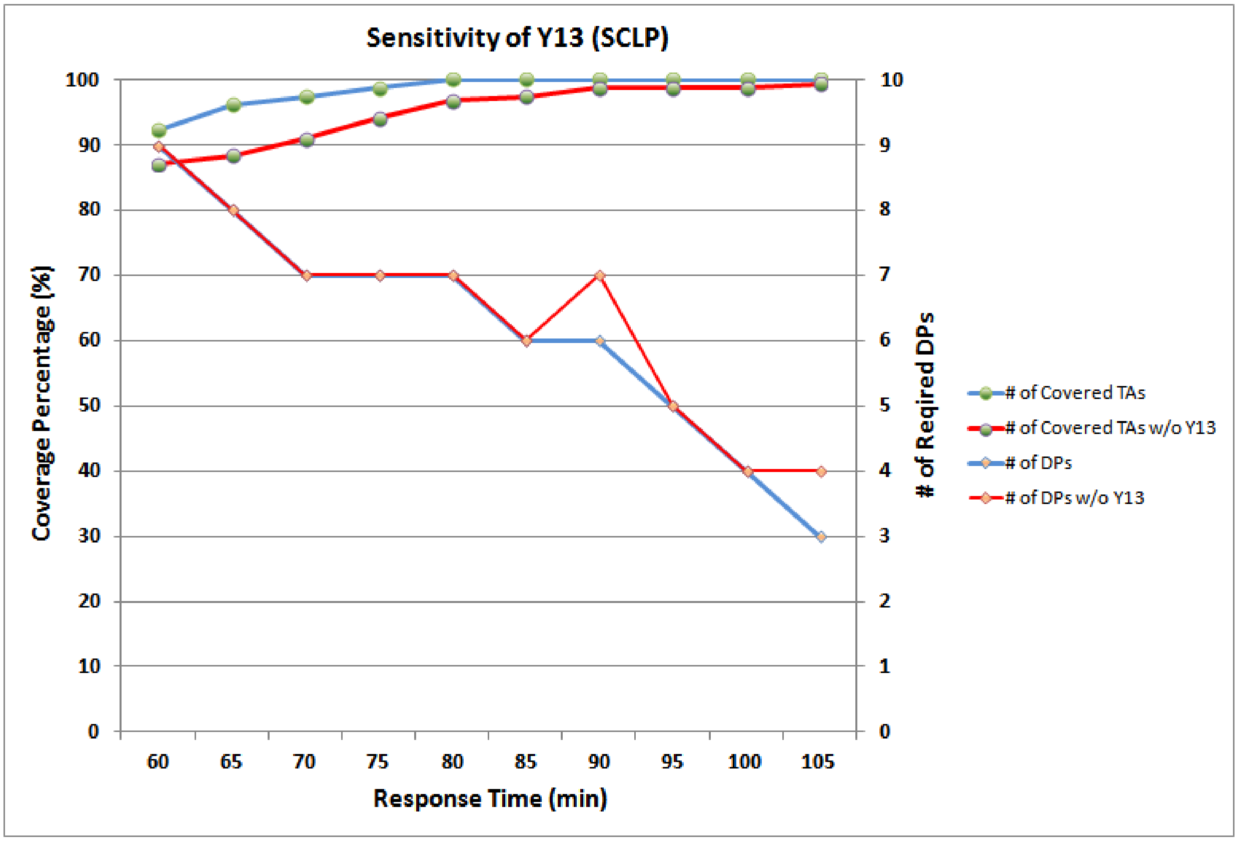

Figure 17. Sensitivity Analysis for Y_{13}

The absence of Y_{13} does not substantially affect the number of required DPs to cover all TAs, but it significantly decreases the number of covered TAs particularly for the response times between 60 and 100 minutes. Since this response time is defined as our reasonable time range, Y_{13} arises as an indispensible DP.

Additionally, Y_{12}, Y_{16}, Y_{17} exist as the most repeating ones with 7 times in 10 solutions due to their central position on the scenario map. Consequently, according the results obtained from SCLP model, our follow on models focus on the 3 to 9 numbers of DPs and 60 to 105-minute response time interval.

4.2.2 Solutions for MCLP Model

Covering as many TAs as we can with a given a number of DPs and response time is the next objective of this research. Dissimilar to other models, the MCLP model has two exogenous variables together, which are response time and number of DPs. After defining our effective research ranges in terms of DPs numbers and response time with the SCLP model, this part of the research presents the results for MCLP model at these ranges.

The covered numbers of TAs for the unweighted MCLP model are shown at Table 7. At least an 80-minute response time and 7 DPs are required to have full coverage as in the SCLP method. The number of covered TAs for 2 DPs does not seem acceptable below 90-minute response time values and the covered TAs numbers are almost same for DP number options above 7. Therefore, our effective range appears to be 3 to 7 in terms of DP number. On the other hand, 60-minute response time gives low coverage and 105-minute response time gives full coverage for all options of this DP number range. Accordingly, 3 to 7 DPs and 65 to 100-minute response time ranges are focus areas of the follow on sections.

Table 7. Numbers of Covered TAs for Unweighted MCLP Model

COVERAGE (# of Covered TAs-Unweighted MCLP)									
		Number of DPs							
		2	3	4	5	6	7	8	9
Response Time (min)	60	96	111	120	128	135	139	141	143
	65	101	116	129	139	145	148	149	149
	70	106	121	133	143	148	151	151	151
	75	110	129	140	148	152	153	153	153
	80	118	138	146	152	154	155	155	155
	85	121	140	147	153	155	155	155	155
	90	124	144	150	154	155	155	155	155
	95	129	149	152	155	155	155	155	155
	100	133	153	155	155	155	155	155	155
	105	138	155	155	155	155	155	155	155

As a subsequent analysis, Figure 18 presents a more precise graph to observe the results for the effective range explained above. Since the coverage lines for 6 and 7 DPs are very closed to each other, 7 DPs option does not offer an appealing trade off. However, it can be preferred though for short response times and acceptable coverage rates if enough capabilities exist.

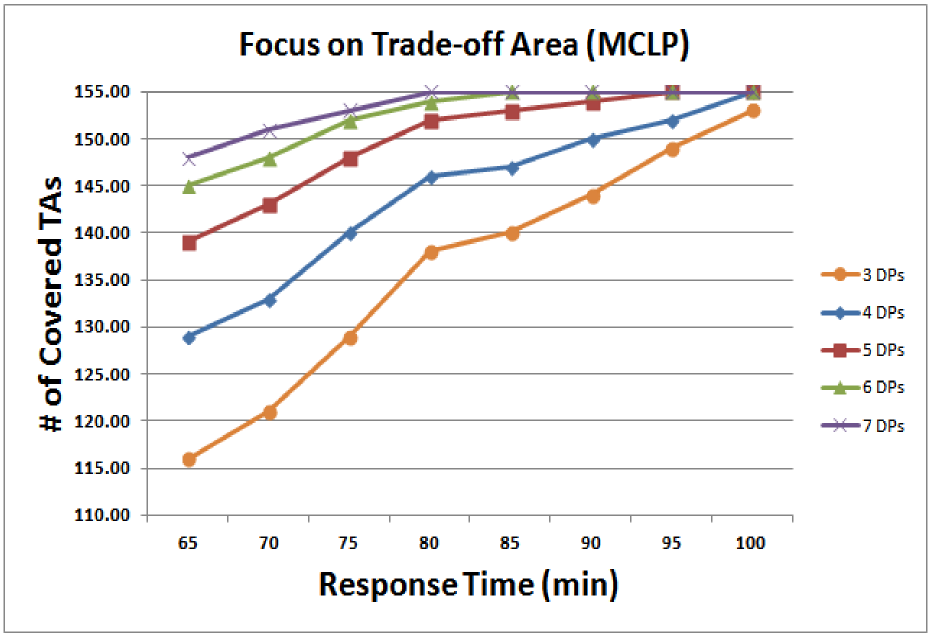

Figure 18. Trade-off s for MCLP

Especially for 3 DPs option, there is an ability to cover 10-15 more TAs for all response time options by adding one more DP. Therefore, our minimum DP number should be at least 4 for maximum coverage rate. For 65 to 75-minute response time and 3 to 5 DPs range, the number of covered TAs increases for 10 additional TAs for each DP increment. This gain can be evaluated worthy to burden an additional DP. It is also possible to obtain close coverage increments for 80 and 85-minute response time cases per each additional DP until 6. In addition, 5 and 6 DPs give remarkable coverage rates for the 85 and 90-minute response time values. These coverage rates can be taken into account in high coverage demanded cases.

Figure 19 presents a graph focusing on the response time effect in the range mentioned above. One can easily see that there is a remarkable ascent from 70 to 75 and 75 to 80-minute cases in terms of number of covered TAs. Also it is possible to reach 140 and above covered TAs for all 4, 5, 6 and 7 DP options with determining a response time above 75 minutes. These values can be brought to better levels with some touch ups on the TA map as mentioned in the SCLP method solutions section.

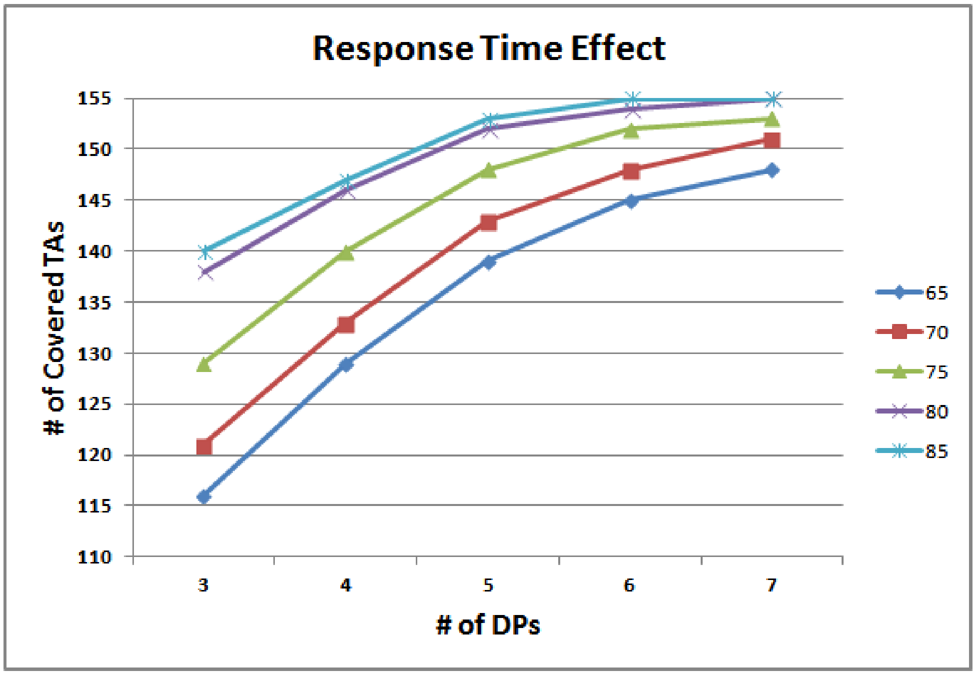

Figure 19. Trade-offs for MCLP (Response Time)

This research also presents a weighed MCLP model application using TAs' assessed risk values. The sectored risk assessment of Turkish Air Space is executed by following the methodology explained in Chapter 3 and the obtained values at Table 4 are used as weighs. The coverage results for weighed MCLP model are shown at Table 8.

Table 8. Numbers of Covered TAs for Weighted MCLP Model

COVERAGE (# of Covered TAs - Weighted MCLP)									
		Number of DPs							
		2	3	4	5	6	7	8	9
Response Time (min)	60	96	111	120	128	135	139	141	143
	65	101	116	129	139	145	148	149	149
	70	106	121	133	143	148	151	151	151
	75	109	129	140	148	152	153	153	153
	80	118	138	146	152	154	155	155	155
	85	121	140	147	153	155	155	155	155
	90	124	144	150	154	155	155	155	155
	95	129	149	152	155	155	155	155	155
	100	133	153	155	155	155	155	155	155
	105	138	155	155	155	155	155	155	155

The weighted coverage results appear to be the same to the ones obtained from the basic MCLP model. This means that our risk values do not affect our objective. There are primarily two reasons for this ineffectiveness. At first, all risk values we obtained are not very different from each other. In other words, some of them should be at least two times bigger than a few of them. The algorithm of integer programming can only prefer one of the TAs instead of two of them in this case. Thus, there happen to be higher demanded objective value with a lower number of covered TAs. The second reason is the dilemma in our technique to assign the risk values of TAs. We assign risk values to TAs according to sectors they exist in. However, the basic reason for having a high-risk value for a sector is containing many TAs in itself. Therefore, sectors that TAs exist in have close risk values to each other and all TAs have close values inherently. Consequently, a comprehensive risk assessment research that assesses each TA independently would presumably give beneficial results for weighed MCLP model.

Risk values are rearranged with a basic formulation that makes them separate to be sure that our research weighted MCLP model is running correctly. The formulation is;

$$R_{new} = [(R_{old} - R_{min}) / (R_{max} - R_{min})] * 100) \quad (4.1)$$

Where; R_{old} is the risk value obtained in Chapter 3, R_{min} is the minimum and R_{max} is the maximum risk value among all TAs. This formulation provides risk values that range from 1 to 100. Thus, a trial to justify the correctness of our weighted MCLP model can be executed. The results obtained from rearranged weighted MCLP model are shown at Table 9.

Table 9. Numbers of Covered TAs for Rearranged Weighted MCLP Model

COVERAGE (# of Covered TAs - Rearranged Weighted MCLP)									
		Number of DPs							
		2	3	4	5	6	7	8	9
Response Time (min)	60	96	111	118	126	135	137	139	143
	65	101	116	129	139	145	146	149	149
	70	104	119	133	143	148	151	151	151
	75	109	129	140	148	152	153	153	153
	80	113	138	144	152	154	155	155	155
	85	121	140	146	153	155	155	155	155
	90	123	143	148	154	155	155	155	155
	95	129	149	152	155	155	155	155	155
	100	133	153	155	155	155	155	155	155
	105	138	155	155	155	155	155	155	155

When the results are examined in a detailed way, it is seen that the number of covered TAs are less for some cells when compared to unweighted model. This justifies that our model runs appropriately. As an another justification method, the aggregate risk values are compared as shown at Table 10.

Table 10. Comparison of Objective Values for Weighted & Unweighted MCLP Models

Aggregate Covered Risk Value-Unweighted								
	Number of DPs							
Response Time (min)	2	3	4	5	6	7	8	9
60	7276	8376	8992	9624	10320	10440	10608	10752
65	7732	8832	9664	10440	11016	11064	11116	11116
70	7768	8896	10012	10760	11196	11244	11244	11244
75	8028	9764	10452	11084	11308	11324	11324	11324
80	8604	10308	10788	11276	11388	11404	11404	11404
85	8896	10476	10884	11372	11404	11404	11404	11404
90	9024	10544	11120	11388	11404	11404	11404	11404
95	9392	10948	11116	11404	11404	11404	11404	11404
100	9780	11212	11404	11404	11404	11404	11404	11404
105	10188	11404	11404	11404	11404	11404	11404	11404

Aggregate Covered Risk Value-Weighted								
	Number of DPs							
Response Time (min)	2	3	4	5	6	7	8	9
60	7276	8376	9072	9704	10320	10488	10632	10752
65	7732	8832	9744	10520	11016	11068	11116	11116
70	7956	9084	10012	10760	11196	11244	11244	11244
75	8368	9764	10452	11084	11308	11324	11324	11324
80	8648	10308	10796	11276	11388	11404	11404	11404
85	8896	10476	10964	11372	11404	11404	11404	11404
90	9088	10608	11148	11388	11404	11404	11404	11404
95	9392	10948	11236	11404	11404	11404	11404	11404
100	9780	11212	11404	11404	11404	11404	11404	11404
105	10188	11404	11404	11404	11404	11404	11404	11404

For the weighted MCLP model, the aggregate risk values become greater than or equal to the unweighted ones as expected. This results justifies that weighted MCLP model runs in a correct logic but needs a risk assessment made independently for each TA to provide realistic results.

According to the results obtained from MCLP model so far, Table 11 presents the names of DPs for the determined trade-off area. Similar to the SCLP model solutions, Y_9, Y_{10}, Y_{13}, Y_{16}, and Y_{17} exist in most of the solutions due to their indispensible positions. Particularly Y_9, Y_{13}, and Y_{16} are most recurrent DPs existing in 18 of 20 results.

Table 11. Assigned DPs by MCLP Model

# of DPs	Response Time (min)	Assigned DPs	# of Covered TA's	# of Uncovered TA's	Name Of Uncovered TAs
3	65	Y9, Y10, Y16	116	39	X1, X2, X3, X4, X5, X6, X89, X92, X94, X95, X96, X97, X99, X100, X101, X102, X103, X104, X105, X106, X107, X108, X109, X110, X111, X133, X134, X135, X136, X137, X138,X139, X140, X141, X142, X152, X153, X154, X155
	70	Y9, Y13, Y17	121	34	X1, X2, X3, X4, X5, X6, X8, X10, X11, X80, X81, X82, X83, X84, X85, X86, X104, X106, X108, X109, X121, X122, X123, X124, X125, X126, X127, X128, X129, X131, X152, X153, X154, X155
	75	Y9, Y10, Y16	129	26	X1, X3, X4, X94, X95, X97, X100, X101, X102, X106, X107, X108, X109, X110, X111, X134, X135, X136, X137, X138, X139, X140, X142, X153, X154, X155
	80	Y9, Y10, Y16	138	17	X4, X94, X95, X100, X101, X102, X109, X110, X111, X135, X136, X137, X138, X139, X140, X154, X155
	85	Y9, Y10, Y16	140	15	X95, X100, X101, X102, X109, X110, X111, X135, X136, X137, X138, X139, X140, X154, X155
4	65	Y9, Y10, Y13, Y16	129	26	X1, X2, X3, X4, X5, X6, X92, X103, X104, X106, X108, X109, X133, X134, X135, X136, X137, X138, X139, X140, X141, X142, X152, X153, X154, X155
	70	Y8, Y9, Y13, Y17	133	22	X83, X84, X85, X86, X104, X106, X108, X109, X121, X122, X123, X124, X125, X126, X127, X128, X129, X131, X152, X153, X154, X155
	75	Y8, Y9, Y13, Y16	140	15	X85, X86, X106, X108, X134, X135, X136, X137, X138, X139, X140, X142, X153, X154, X155
	80	Y9, Y10, Y13, Y16	146	9	X4, X135, X136, X137, X138, X139, X140, X154, X155
	85	Y8, Y9, Y13, Y16	147	8	X135, X136, X137, X138, X139, X140, X154, X155
5	65	Y9, Y10, Y13, Y16, Y18	139	16	X1, X2, X3, X4, X5, X6, X92, X103, X104, X106, X108, X109, X152, X153, X154, X155
	70	Y8, Y9, Y13, Y16, Y17	143	12	X83, X84, X85, X86, X104, X106, X108, X109, X152, X153, X154, X155
	75	Y8, Y9, Y13, Y16, Y17	148	7	X85, X86, X106, X108, X153, X154, X155
	80	Y9, Y10, Y13, Y16, Y25	152	3	X4, X154, X155
	85	Y9, Y10, Y13, Y16, Y17	153	2	X154, X155
6	65	Y4, Y9, Y10, Y13, Y16, Y18	145	10	X92, X103, X104, X106, X108, X109, X152, X153, X154, X155
	70	Y4, Y10, Y11, Y13, Y16, Y17	148	7	X104, X106, X108, X109, X153, X154, X155
	75	Y9, Y10, Y13, Y16, Y17, Y23	152	3	X106, X108, X155
	80	Y9, Y13, Y14, Y16, Y18, Y23	154	1	X155
	85	Y10, Y11, Y13, Y16, Y17, Y23	155	0	

A sensitivity analysis of Y_9, Y_{13}, and Y_{16} for 5 DPs case is executed because of their existence in all results of this case. Results are shown at Figure 20.

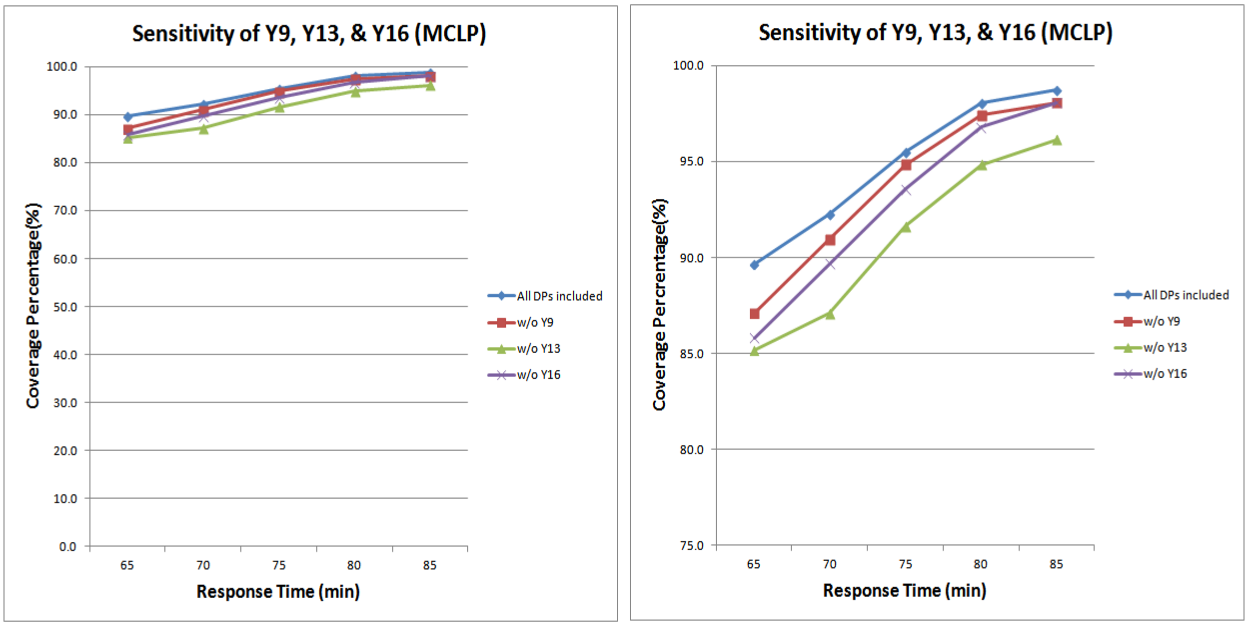

Figure 20. Sensitivity Analysis of Y_9, Y_{13}, and Y_{16} for MCLP Model

Since all results for Y_{13}'s absence are the lowest values, the research's given scenario is most sensitive to Y_{13} again. Almost 5% of coverage is lost for all response time cases because of Y_{13} absence. It can be stated that Y_{16} is the second important DP for 5 DPs case when Figure 20 is examined.

Comparison of the options, which have higher number of covered TAs than 140, gives us the names of the problem TAs. Especially checking the ones that have 10 or below uncovered TAs allows us to identify the outlier TAs. The ones close to X_{85}, X_{106}, and X_{155} symbolizes the different points of three training areas at the south and north edges. As advised in the SCLP solution section, little shifts for these three areas may bring in a few more coverage percentage. Additionally authorities can avoid 1 more DP assigning to obtain the same coverage.

As a result of the MCLP model, at least 4 or more SAR units should be assigned within our scenario to have acceptable coverage rates for reasonable response times between 60 and 85 minutes. The marginal benefit on the coverage rate for 1 more DP from 3 to 4 shouldn't be

ignored. 5 DPs option should be taken into account if full coverage is demanded with little shifts of a few TAs.

4.2.3 Solutions for P-Median Model

This research's last objective is minimizing the total or average response time of SAR system within a given number of DPs. The actual intention to find the minimum total response time is to expose the optimum locations of SAR units for the given scenario.

Before determining locations, Figure 21 presents a chart that illustrates the response time distribution in case of 4 DPs located. To obtain this chart, bins of 5 minute response times are generated and the assigned response times are rounded to the closest bin. The frequency is calculated by repetition of these bins. If 4 DPs are located, the maximum response time of the system is almost 125 minutes. The frequency shows the repeating number of each bin. For example, there are 19 TAs, which are in the offset of almost 45-minute response time for the 4 DPs case. Additionally, almost 50 percent of TAs are closer than 45-minute and 90 percent of them are closer than 75-minute response time to the assigned DPs.

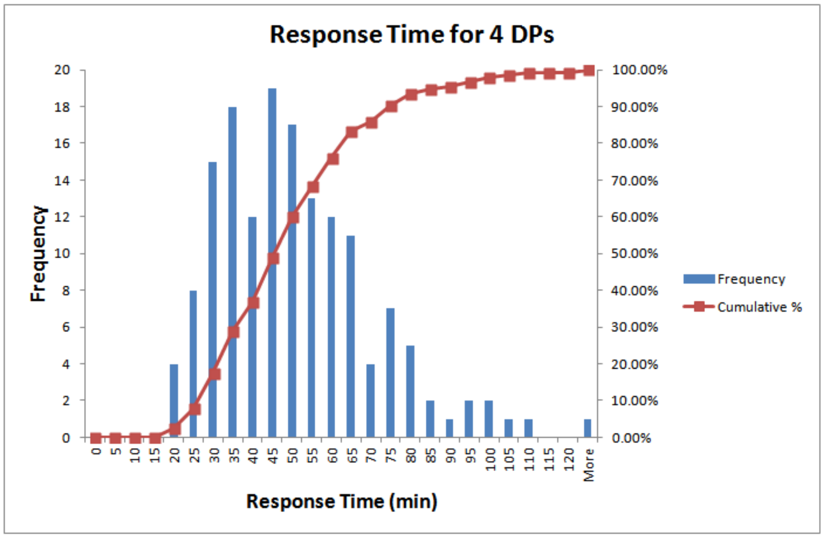

Figure 21. Response Time Distribution for 4 DPs

Figure 22 presents the results of P-median model for the 5 DPs case. A significant decrease in response times rises out. The frequencies becomes more similar to a normal distribution and the maximum response time value goes down more than 30 minutes. Additionally, almost 53 percent of TAs are closer than 45-minute and 95.5 percent of them are closer than 75-minute response time to the assigned DPs. The 5.5 percent gain is a good value when compared with the 4 DP case which means 8 more TAs becomes closer than 75-minute response time.

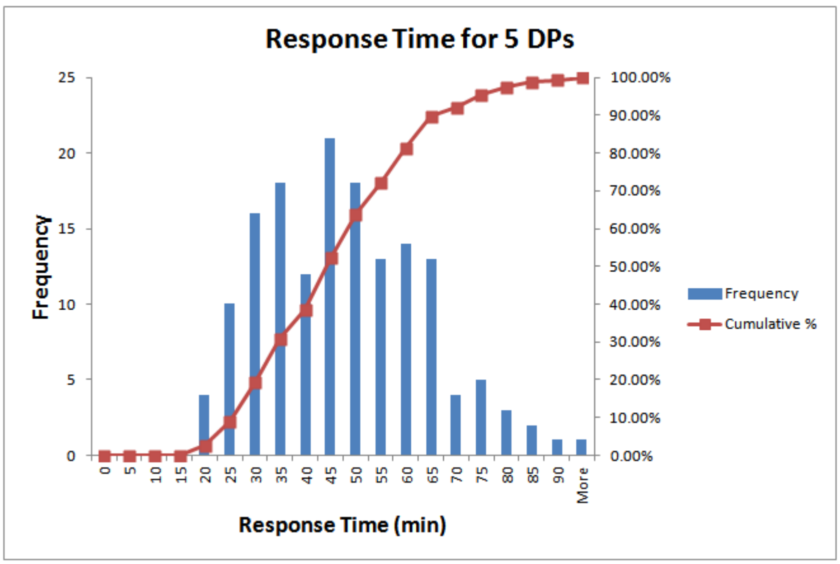

Figure 22. Response Time Distribution for 5 DPs

Figure 23 presents the results of P-median model for the 6 DPs case. Histogram seems to be more accumulated in the mid response time values. The maximum response time value does not change because of two TAs. Additionally, one more DP shifts the curve a little left to smaller response time values. However, there is not a valuable effect of one additional DP since it does not change significantly the maximum and average response time values.

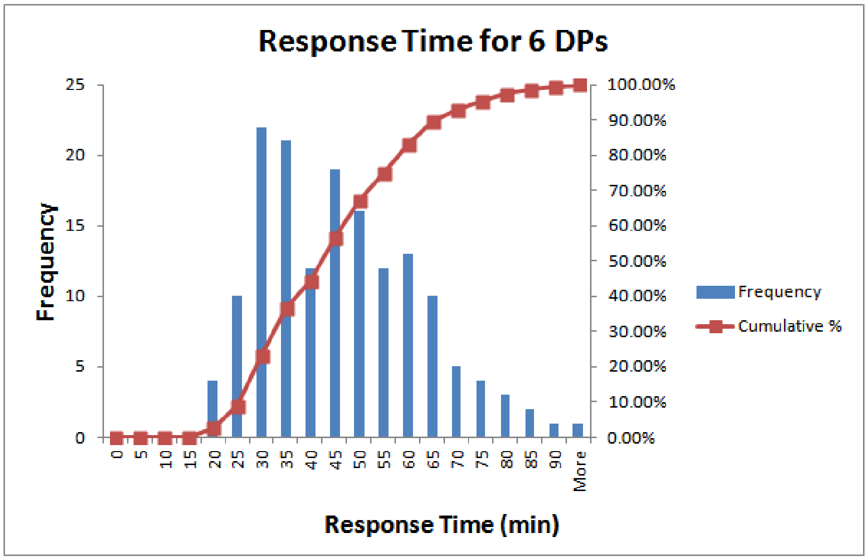

Figure 23. Response Time Distribution for 6 DPs.

The combined illustration of all DPs number cases is presented in Figure 24. One can easily realize that there is a significant effect of enhancing the DP number from 3 to 4 in terms of coverage rate for the reasonable response times determined in previous models applications. This effect can be also seen between 4 and 5 comparison. 5 DPs and 6 DPs cases results appear as almost same. Even though 7 DPs case provides a coverage increment in a small scale, bearing the burden of 2 additional DPs may not worth this small scale increase. Thus, 5 DPs option seems to be most effective option for our scenario in terms of coverage rate.

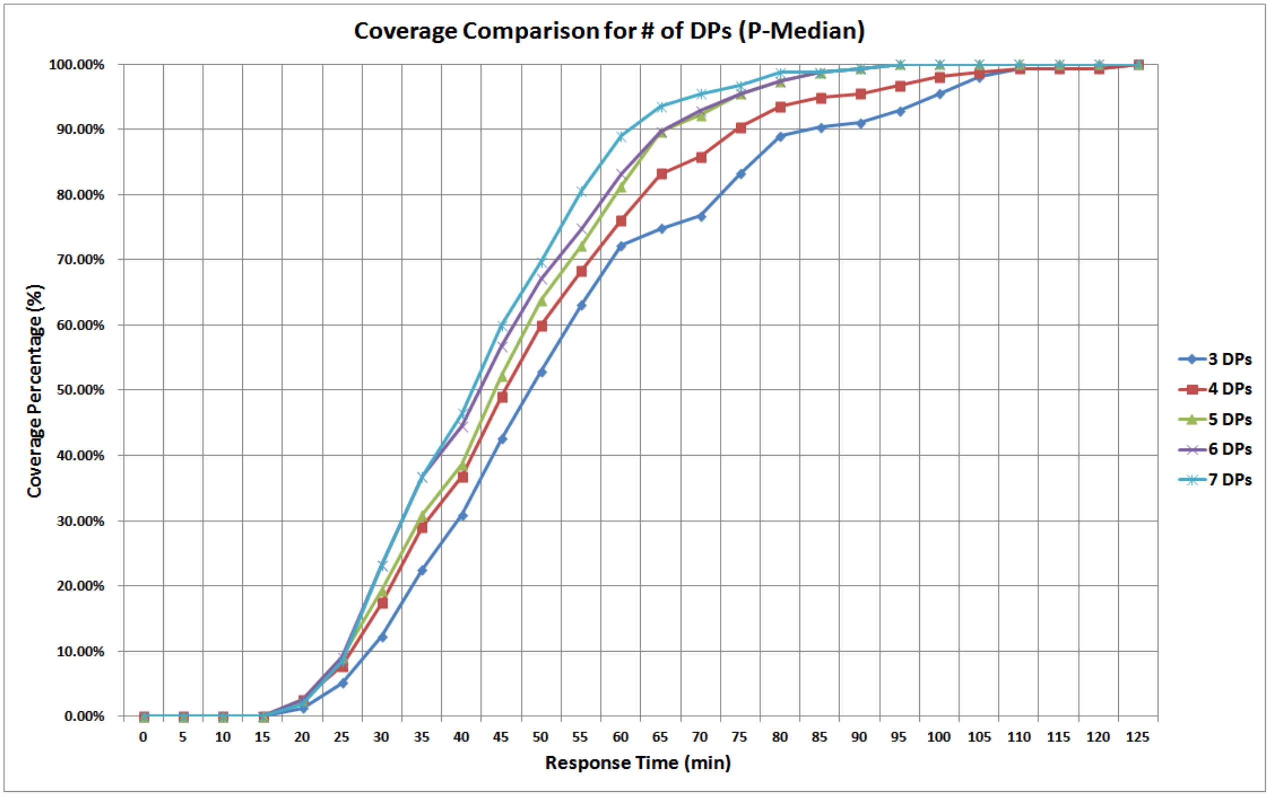

Figure 24. Coverage Comparison for # of DPs with P-Median Model

Table 12 gives the quantitative results of the P-median model. The 5 DPs case provides a significant decrease in terms of average and worst case response time. The second step to obtain a significant effect can be defined with 8 DPs option to improve the worst case response time value.

Table 12. Results of P-Median Model

	Average Response Time(Min)	Median Response Time (min)	Worst Case Response Time (min)	Assigned DPs
3	52.7	48.3	124.3	Y9, Y10, Y16
4	48.3	45.3	125.3	Y8, Y9, Y13, Y16
5	45.3	44.4	91.2	Y8, Y9, Y13, Y16, Y18
6	43.9	41.6	91.2	Y8, Y9, Y11, Y13, Y16, Y18
7	42.6	41.1	91.2	Y7, Y9, Y10, Y11, Y13, Y16, Y18
8	41.3	40.2	76.2	Y7, Y9, Y10, Y11, Y12, Y13, Y16, Y18

Figure 25 shows the results by means of lines. The largest decrease in worst case and average response time is executed by an additional DP, from 4 to 5 DPs.

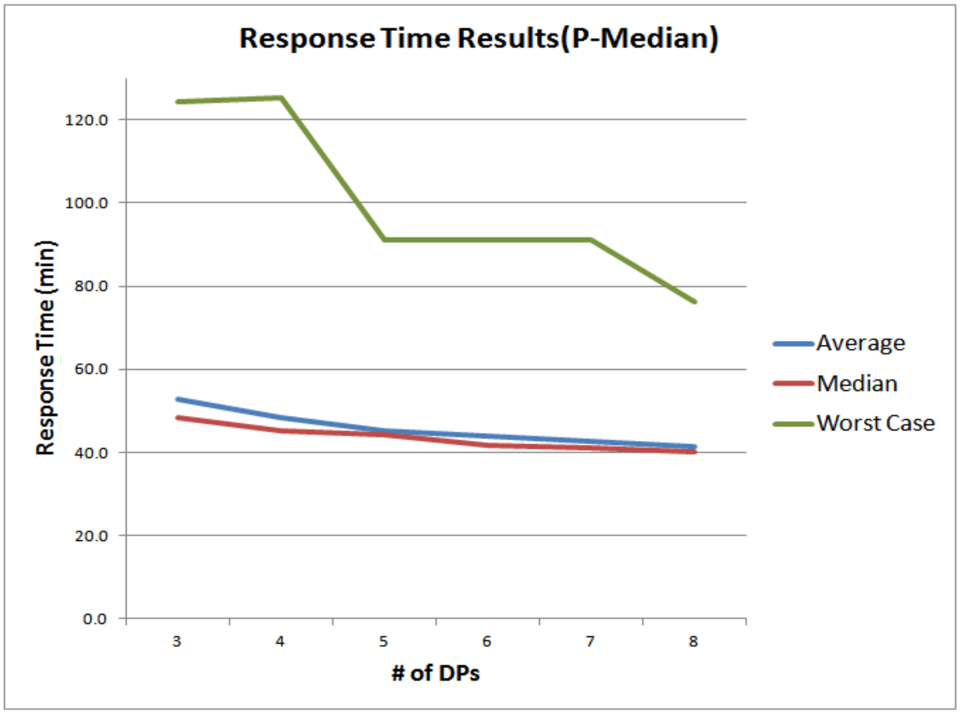

Figure 25. P-Median Results Chart

Since we justified with the SCLP, MCLP, and P-Median models that 5 DPs is a preferable alternative, the next step is determining the names of these locations which is the primary objective of the P-median model. The P-median model gives the names of DPs as Y8, Y9, Y13, Y16, and Y18. It is an outstanding point that the first four are the most repeating ones in the SCLP and MCLP models. Y_{18} appears as an exception with P-median to minimize the aggregate distance.

A sensitivity analysis of Y_9, Y_{13}, and Y_{16} for the P-median model is executed because of their existence in all results except Y_{13}'s nonexistence for 3 DPs case. Figure 26 illustrates the results of sensitivity analysis for P-median model.

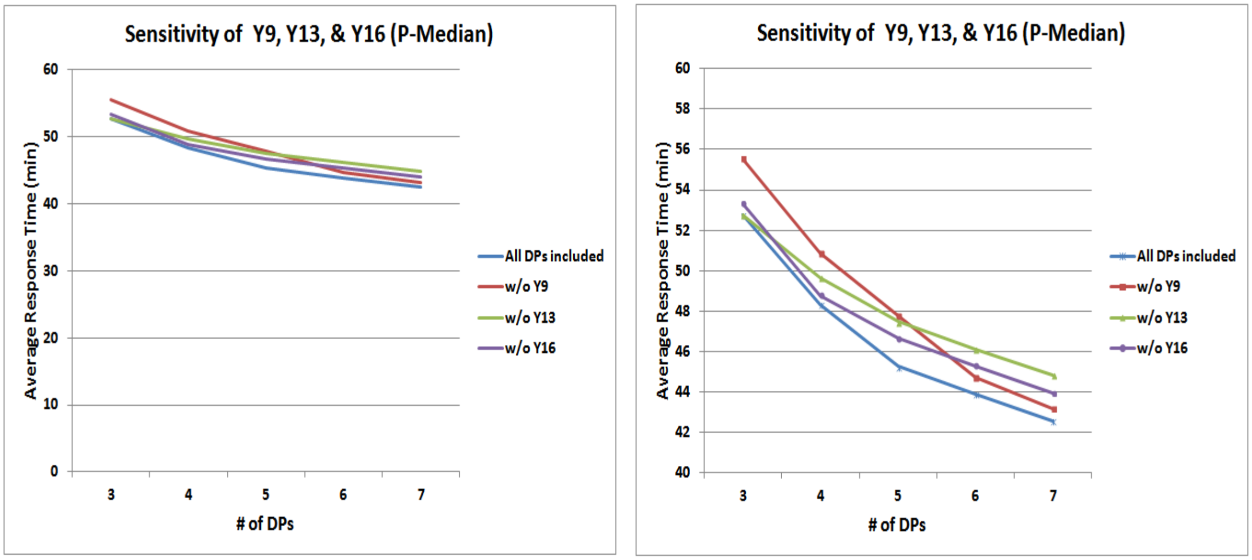

Figure 26. Sensitivity Analysis of Y_9, Y_{13}, and Y_{16} for P-Median Model

According to the results obtained from sensitivity analysis, Y_9 is the most sensitive DP for 3, 4, and 5 DPs cases. For the 6 and 7 DPs cases, Y_{13} becomes the most sensitive one. This alteration is because of Y_9's central position. The model keeps it in the solution set to minimize the aggregate response time for lower number of DPs. For higher number of DPs, another DP can be chosen instead of Y_9. For this case Y_{13}'s indispensible position becomes more important for the P-median model.

4.3 Comparison of SCLP, MCLP, and P-Median Results

In this section of the research, results are shown for all three models in a combined illustration. The results range is bounded to 4 to 6 DPs and 70-85 minute-response times since it is justified as the effective trade off range for all models.

Table 13 presents the results for SCLP, MCLP, and P-median models for the defined effective trade off range. The SCLP model proves that it is not possible to cover all TAs with

less than 7 DPs. However, it can inherently be possible to cover all with a smaller number of DPs if the response time is extended as seen for the example of 85-minute response time case.

Since it may not be possible to assign 7 SAR units due to budget constraints, this research seeks for some ways to maximize coverage with less DPs. Accepting some flexibility on the response time variable and making some little shifts for a few TAs on the given map may save up to 2 DPs. Almost full coverage can be obtained by the MCLP model via these arrangements with 5 DPs for a 75-minute response time while the required number is 7 for the SCLP model. Most of 7 uncovered TAs can be covered after making stated little shifts.

Table 13. Effective Range Results for All Models

	SCLP			MCLP		P-MEDIAN			
Response Time (min)	Required # of DPs for Full Coverage	Assigned DPs	# of Assigned DPs	# of Covered TAs	Assigned DPs	# of Covered TAs	Average Response Time (min)	Assigned DPs	Repeating DPs in all Solutions
70	7	Y6, Y10, Y12, Y13, Y16, Y17, Y24	4	133	Y8, Y9, Y13, Y17	133	48.3	Y8, Y9, Y13, Y16	Y13, Y16
			5	143	Y8, Y9, Y13, Y16, Y17	143	45.3	Y8, Y9, Y13, Y16, Y18	
			6	148	Y4, Y10, Y11, Y13, Y16, Y17	144	43.9	Y8, Y9, Y11, Y13, Y16, Y18	
75	7	Y4, Y9, Y10, Y12, Y13, Y16, Y17	4	140	Y8, Y9, Y13, Y16	140	48.3	Y8, Y9, Y13, Y16	Y9, Y13, Y16
			5	148	Y8, Y9, Y13, Y16, Y17	148	45.3	Y8, Y9, Y13, Y16, Y18	
			6	152	Y9, Y10, Y13, Y16, Y17, Y23	148	43.9	Y8, Y9, Y11, Y13, Y16, Y18	
80	7	Y9, Y10, Y12, Y13, Y15, Y16, Y24	4	146	Y9, Y10, Y13, Y16	145	48.3	Y8, Y9, Y13, Y16	Y9, Y13, Y16
			5	152	Y9, Y10, Y13, Y16, Y25	151	45.3	Y8, Y9, Y13, Y16, Y18	
			6	154	Y9, Y13, Y14, Y16, Y18, Y23	151	43.9	Y8, Y9, Y11, Y13, Y16, Y18	
85	6	Y6, Y8, Y12, Y13, Y15, Y16	4	147	Y8, Y9, Y13, Y16	147	48.3	Y8, Y9, Y13, Y16	Y13, Y16
			5	153	Y9, Y10, Y13, Y16, Y17	153	45.3	Y8, Y9, Y13, Y16, Y18	
			6	155	Y10, Y11, Y13, Y16, Y17, Y23	153	43.9	Y8, Y9, Y11, Y13, Y16, Y18	

Although the coverage range is not an issue of the P-median model, the number of uncovered TAs can be observed from the solution set. When the results of the MCLP and P-median models

are compared, it is evident that the MCLP model covers equal or more TAs than the P-median as expected.

The P-median model primarily aims to find the optimum locations to minimize the aggregate response time for the whole system. The average response time is 48.3 minutes for 4 DPs option. A significant decrease to 45.3 minutes appears when the number of DPs enhanced to 5. But the decrease in response time is minor when 6 DPs option is activated. It provides a decrement of 1.4 minutes for average response time when the DPs number is enhanced to 6. As in the previous models, enhancing the DPs number from 4 to 5 seems to worth it to take the burdens of an additional DP. However, it cannot be interpreted the same for the enhancement from 5 to 6 DPs. But still 6 DPs can be assigned due to its marginal benefit if there is enough capability.

In addition to DPs number evaluations, marginal benefits of response time values should not be ignored. One can observe from Table 13 that there is significant increment in number of covered TAs for both MCLP and P-Median models when response time is extended to 75 from 70. This increment does not go in the action for the follow on 5 minute additions. Thus, 75-minute response time seems to be the best option in terms of coverage and quick reaction capability.

Finally, the last objective of the research is defining the names of DPs to generate the SAR DP location map. As seen in Table 13, there are some DPs that exist in almost all solutions of three applied models. Y_{13} and Y_{16} appear as the exceptional TAs with existing in every solution set. Also, Y_9 exists in all 75 and 80 minute solution sets. Another remarkable location is Y_8. It exists in all solution sets for the P-median model which is our basic model to define the names of locations. Another notable result is that Y_{18} exists in the P-median model solutions for 5 and 6

DPs while it never shows up in the solution sets of other models. This means that it has a lower approximate distance to the TAs around itself but it is distant to a few problem TAs. Therefore, Y_{18} can also exist in other models' solution sets after making stated arrangements on the TA map.

4.4 Summary

This chapter presents the results of the SCLP, MCLP, and P-Median models' applications to the given scenario. The results are given and interpreted separately for each model. Afterwards, a comparison of the effective trade off range, which is determined by these three models, is figured out to see the similarities and the differences of the results. Consequently, the most outstanding option for the number of DPs and response time pair is reported. The location names mostly preferred by models also are stated and compared.

V. Conclusions and Recommendations

5.1 Summary

Chapter 1 gives general information about Turkey and TUAF capabilities. The problem area is explained and importance of SAR units for air forces is emphasized as well. The assumptions of the research are also defined in Chapter 1.

Chapter 2 presents a literature review about location problem types. Comprehensive explanations of the applied three models are given with their mathematical formulations, as they exist in the literature. Since the risk values of TAs are used in the MCLP model as weighs, Chapter 2 also introduces basic risk assessment methods.

Chapter 3 firstly explains the applied methods to generate the parameters of the research's problem. Then it presents the modified mathematical models which are figured out to fit the research's problem. Subsequently Chapter 3 presents risk value generation method of the research. Lastly it introduces the generated VBA & LINGO interface used to have results.

Chapter 4 presents the results of the applied models. An effective range of response time and number of DPs is stated. Comparison of all models for this range is interpreted as well.

Chapter 5 states conclusions and recommendations. The obtained ideas for further researches are also presented.

5.2 Research Conclusions

Location problems are very common in the deterministic optimization area. Military location problems are one the most applied applications of location problems as well. Since our problem

is about optimizing the TUAF SAR DP locations, this research originates from applied similar military location problems.

The SCLP method is applied to find the minimum number of DPs to cover all TAs in the given scenario. This method determines the minimum number of DPs as at least 7 to cover all TAs. Another take away from the results of the SCLP method is the minimum response time, 80 minutes, to cover all TAs. This means that it is not possible to cover all TAs within a range smaller than 80-minute response time even when using all given 25 DP options. However, it is remarkable that response times between 65-80 minutes provide coverage higher than 90 percent. Hence, this response time range is valuable to research.

The MCLP method aims to have maximum coverage with limited number of DPs and a defined response time. The primary concern of the MCLP method is to supply some Decision Support Systems (DSS) to decision makers in constrained capability cases. The MCLP method provides low coverage for 3 DPs option. In addition to 3 DPs option, 7 DPs option gives almost full coverage above 70-minute response time. Hence the effective range is determined as 4 to 7 DPs in terms of DPs number. On the other side 65-minute response time option gives low coverage for all DPs numbers. On the contrary case, 95-minute option gives almost full coverage for all DPs numbers. Thus, the effective range for response time is determined as 70 to 85-minutes. The most effective options obtained from MCLP method are 5 DPs and 75-minute response time according the their marginal benefit on coverage.

The MCLP method is also applied in a weighed approach with generated sectoral risk values. Since our obtained risk values are very close to each other, the results are the same as in unweighted model. The sectoral approach for risk values caused to close values, since the

existence of TAs makes relevant sector risky and assignment of that sector's value to containing TAs makes TA values close which is somewhat a vicious circle. Therefore, a risk study which consists of many more sectors or which assesses every TA independently may reveal better solutions in terms of weighed coverage.

The P-median model's objective is to find the minimum aggregate response time as an expression of an effective system. At the same time, it determines the best locations to reach this objective. This research's model presents that the 5 DP option is the best option in terms of total response time and Y_8, Y_9, Y_{13}, Y_{16}, and Y_{18} are the best location names for this option.

Since this research depends on a notional generic TA map, the VBA & LINGO interface is figured out very flexible to change all parameters. It is applicable for all basic location problems after entering demand point and candidate point coordinates. Hence, this interface can easily be applied with the real data of the researches problem.

As a result of comparing results of all applied models, between 3 to 7 DPs, one additional DP significantly effects the coverage and total response time. Especially the increment from 4 to 5 DPs has a considerable impact on coverage. The same case is valid for the response times 70 to 75 minutes. Another point of view for response time is that our SAR units reaction time which appears as constant cost. After observing with all models that every minute is important for coverage, the authorities should look for some ways to diminish the reaction time. 5-minute gain in reaction may easily result to save up one more DP.

Although our TAs map is generic, conclusion of rearranging the outlier TAs is the fact. This conclusion may most probably be obtained via the application of any country's air space.

Decision makers should take into consideration of shifting TAs to obtain full SAR coverage with lower number of SAR DPs.

5.3 Recommendations for Future Researches

This research presents a location optimization methodology for SAR DPs, which are assumed equal logistically and geographically. The logistical and maintenance issues have critical effect on the concerns of decision makers to locate their military facilities. The research area can be extended by adding some logistical and geographical values to candidate points.

This research observes results for every response time option within 5-minute intervals. A study may be developed to apply different required response times for each TA or defined sector. Different response times can be determined via the risk of geography of relevant TA. Additionally, a comprehensive risk evaluation research may be very beneficial when applied to this research's models. But this research requires to have distinct risk values for each TA.

If the decision makers decide the exact locations of SAR DPs, a research can be done for regenerating the fighter aircrafts TA map. Since the TAs have lots of restrictions about their size, distance to bases, types of mission etc., generating a TA map with the concern of fuel efficiency and attainability of SAR units may reveal a valuable contribution to Air Forces.

OPTIMIZATION OF TUAF SAR UNITS' FORWARD DEPLOYMENT POINTS FOR A CENTRAL BASED SAR FORCE STRUCTURE

Capt. Mustafa ACAR (TUAF)
Advisor: Dr. Jeffery D. Weir
Reader: Maj. Jennifer L. Geffre
Department of Operational Sciences (ENS)
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RESEARCH QUESTION

What is the optimum number of SAR units and their locations to maximize SAR service coverage on fighter aircraft training areas while minimizing the average response time?

OBJECTIVES

- Defining the minimum number of SAR DPs to cover all TAs
- Obtaining maximum demanded coverage with a given number of SAR DPs and a given response time
- Defining the locations for given number of SAR DPs while obtaining minimum average response time

VBA & LINGO INTERFACE

- A user friendly VBA & LINGO interface to flexibly change exogenous variables for each model and to have results for very short intervals of variable values
- Provides an easy application of three models for all basic location problems after inputting the coordinate data of demand and candidate points

SCLP APPLICATION

- Minimize $\sum_{j \in J} X_j$
- Subject to $\sum_{j \in N_i} X_j \geq 1 \quad \forall i \in I$; $X_j \in \{0,1\} \quad \forall j \in J$; $X_1 = 1$

MCLP APPLICATION

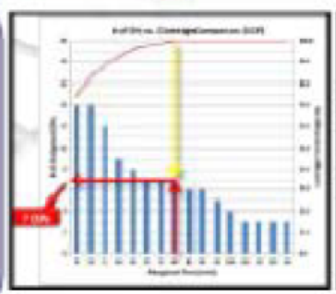
- Maximize $\sum h_i Y_i$
- Subject to $Y_i - \sum_{j \in N_i} X_j \leq 0 \quad \forall i \in I$; $\sum X_j = P$; $X_j \in \{0,1\}$; $Y_i \in \{0,1\}$; $X_1 = 1$

P-MEDIAN APPLICATION

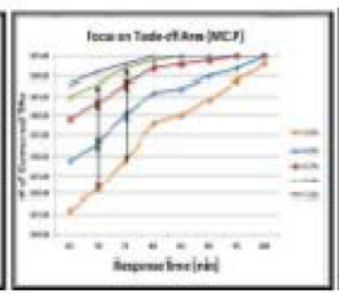
- Minimize $\sum\sum h_i d_{ij} Y_{ij}$
- Subject to $\sum_j Y_{ij} = 1 \quad \forall i \in I$; $\sum X_j = P$; $X_j \in \{0,1\}$; $Y_{ij} \in \{0,1\}$; $X_1 = 1$

RESULTS OF APPLIED MODELS

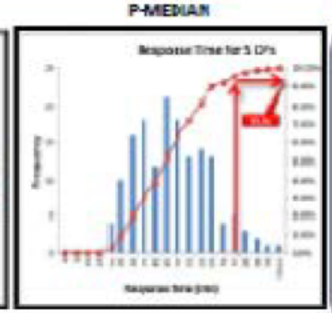
SCLP



MCLP



P-MEDIAN



CONCLUSIONS

- Each 5 minute addition in response time has almost the same effect on the objective values as adding a DP
- The increment from 4 to 5 DPs has a considerable impact on coverage and average response time
- The increment in response time from 70 to 75 minutes has the similar effect on coverage
- Shifting a few TAs may result to obtain full SAR coverage with 5 SAR DPs

FUTURE RESEARCH

- An extended research by adding some logistical and geographical values to candidate points
- Applying different required response times for each TA or defined sector
- Regenerating the map of fighter aircraft TAs

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Vita

Captain Mustafa ACAR was born in Samsun in 1981. He graduated from Maltepe Military High School in 1998. With graduation from Turkish Air Force Academy in 2002, he earned the degree of Bachelor of Science in Industrial Engineering. In the same year, he began his flight training in 2nd Main Jet Base in Izmir. After graduating from the flight training school, he was assigned to the 5th Main Jet Base's Search and Rescue Squadron, Merzifon as a search and rescue pilot. He joined the Turkish Air Staff College in 2009 and graduated in 2011 as a staff officer. Afterwards, he worked in Turkish General Staff Headquarter as a NATO Plan Officer at J-3 Plans & Ops Division for two years. He entered Graduation School of Engineering and Management, Air Force Institute of Technology in 2013.

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14. ABSTRACT

Many developed countries that have a combatant Air Force and Search & Rescue (SAR) assets designed for their Air Force’s SAR service have been struggling with locating SAR units due to limited SAR assets, constrained budgets, logistic-maintenance problems, and high-risk level of military flights. In recent years, the Turkish Air Force (TUAF) has also been researching methods to gather all SAR units into a central base and deploying the needed number of SAR units to defined Deployment Points (DPs).

This research applies three location optimization models to determine the optimum locations for TUAF SAR units. The first model, Set Covering Location Problem (SCLP), defines the minimum number of SAR DPs to cover all fighter aircraft training areas (TAs). The second model, Maximal Covering Location Problem (MCLP), aims to obtain maximum coverage with a given SAR DP number and response time. A weighted MCLP models is also applied with TAs risk values obtained by this research to maximize demanded coverage of TAs. Finally the last model, P-Median Location Problem, defines the locations of SAR DPs while obtaining minimum aggregate or average response time. These three models are applied via a Visual Basic for Applications (VBA) & LINGO Optimization Software interface that allows changing each exogenous variable of the models in a flexible way.

The primary objective of this research is to provide the information for the required number of SAR units and their locations. The results indicate that the response time definition is as important as the required number of DPs. Additionally; some DP locations are indispensible because they have no alternative in their sectors.

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Corrosion, Fatigue, Fracture Mechanics, Crack Initiation, Crack Growth Rate, Aluminum Alloys

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